Report No. CG-D-21-95

IDENTIFICATION OF ALTERNATIVES FOR PHASE II COST AND OPERATIONAL EFFECTIVENESS ANALYSIS

Annex B of Cost and Operational Effectiveness Analysis for Selected International Ice Patrol Mission Alternatives

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FINAL REPORT

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16. Abstract

This report is Interim Report Volume 2 for the Cost and Operational Effectiveness Analysis for Ice Patrol Mission Analysis Study. This report details the development of the alternatives that were considered by the Coast Guard, discusses the evaluation criteria and evaluation process used to select alternatives for further analysis, and identifies the specific alternatives that are to be examined in detail in Phase II of the study as determined by the Program Manager at the Alternatives Selection Meeting on October 14, 1994.

A number of alternatives were considered with respect to management of the IIP, models used by the IIP, data acquisition and processing, and surveillance/detection/classification concerns as they impact the IIP mission of determining and disseminating the Limits of all Known Ice. Criteria of technical feasibility, likelihood of accomplishing the mission element, and reasonable cost were used as discriminators, along with the imperative to select three alternatives.

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METRIC CONVERSION FACTORS

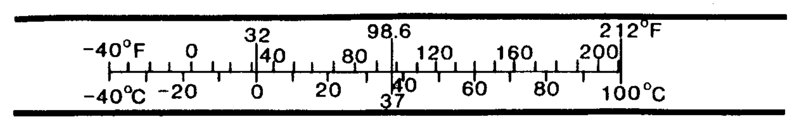
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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IDENTIFICATION OF ALTERNATIVES FOR PHASE II COST AND OPERATIONAL EFFECTIVENESS ANALYSIS

Executive Summary

This report details the development of the alternatives that were considered by the Coast Guard, discusses the evaluation criteria and evaluation process used to select alternatives for further analysis, and identifies the specific alternatives that are to be examined in detail in Phase II of the study as determined by the Program Manager at the Alternatives Selection Meeting on October 14, 1994.

A number of alternatives were considered with respect to management of the IIP, models used by the IIP, data acquisition and processing, and surveillance/detection/classification concerns as they impact the IIP mission of determining and disseminating the Limits of All Known Ice. Criteria of technical feasibility, likelihood of accomplishing the mission element, and reasonable cost were used as discriminators, along with the imperative to select three alternatives.

A decomposition approach was used that identified a larger set of elements. The selected alternatives included:

Management:
- U.S. management with Coast Guard having primary responsibility.
- Canadian management (technically U.S. with Canada subcontracted).
- U.S. management with National Ice Center having primary responsibility.

Modeling:
- Sensitivity analysis and risk structure for system of models.

Data acquisition and processing:
- Implementation of CG version of ADAM system.
- Comparison of upgrading INTERGRAPH system with shifting to ISIS.

Surveillance/detection/classification:
- Brief examination of RADARSAT and Ground Wave Radar.
- USCG surveillance with SLAR/FLAR/SAR.
- Surveillance contracted to Canada.
- Surveillance contracted to commercial firm.

At the same time, as these alternatives are examined from a cost and effectiveness perspective, a similar analysis will be conducted for the current system.

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IDENTIFICATION OF ALTERNATIVES FOR PHASE II COST AND OPERATIONAL EFFECTIVENESS ANALYSIS

1.0 Objective and Purpose of the Report.

This interim report satisfies the requirement of Task 3.8.6 of contract number DTCG39-94-C-E00085 / IIP Mission Analysis. The report details the development of the alternatives that were considered by the Coast Guard, discusses the evaluation criteria and evaluation process used to select alternatives for further analysis, and identifies the specific alternatives that are to be examined in detail in Phase II of the study.

The current operations of the International Ice Patrol (IIP) were described in an Interim Report dated September 2, 1994 (Armacost, Jacob, Kollmeyer, and Super, 1994). The report characterized the various processes used in IIP operations, including the types of information used by the IIP, the data requirements and processes necessary to develop that information, and how the information is provided to the mariner. The report included descriptions of the existing authority, organization, and management of the IIP as well as initial characterizations of the operating cost of the IIP. Because that description of IIP operations is used as a basis for the detailed analysis in Phase II as well as the development of alternatives considered in this report, a summary of the current operations is provided below. Following that summary, the planning assumptions and evaluation criteria that are used in the present analysis are described. Finally, alternatives in several different areas are developed and the results of the evaluation are presented.

An Alternatives Selection Meeting involving the Program Manager, IIP representatives, Coast Guard Research and Development Center (R&DC) representatives, CG Air Station Elizabeth City representatives, and a Commandant (G-EAE) representative was held at the IIP in Groton, CT on October 14, 1994. This report incorporates the results of that meeting and indicates where new alternatives or directions were generated at the meeting. The Statement of Work and the EER Proposal call for identifying three alternatives to examine in detail. The results of the Alternatives Selection Meeting effectively identify more than three alternatives for the Phase II analysis. In addition to conducting a detailed Cost and Operational Effectiveness Analysis (COEA) of those alternatives in Phase II, a detailed COEA of the current operation will also be conducted. This latter analysis will likely yield additional alternatives representing incremental changes to the current system that will be available for the Program Manager's consideration.

2.0 Summary of Current Operations of the IIP.

The basic mission of the IIP is unchanged since the inception of the ice patrol service. Basic authority for conducting the IIP is provided by SOLAS 74, Chapter V, Regulations 5-8 and 46 USC 738, 783(a)-(d). Under provisions of the SOLAS treaty, the

United States is the Managing Government for the IIP. Day to day management responsibility is assigned to the U.S. Coast Guard. Commander, International Ice Patrol, located at Groton, CT operates under the operational control of Commander, Atlantic Area. The IIP operationalizes the IIP mission as ***determining the Limits of All Known Ice along the southeastern, southern, and southwestern edge of the ice region and publishing that information to mariners in a timely fashion***. This mission involves data and information acquisition, processing, and distribution--finding out where the ice danger is for trans-Atlantic shipping and telling the mariner so as to prevent ship-iceberg collisions. The primary products of the IIP are the 0000Z and 1200Z Ice Bulletins and the 1200Z Facsimile Ice Chart that depict the Limits of All Known Ice (LAKI) and positional information on selected icebergs and radar targets. Figure 1 provides a context diagram illustrating these information processing activities.

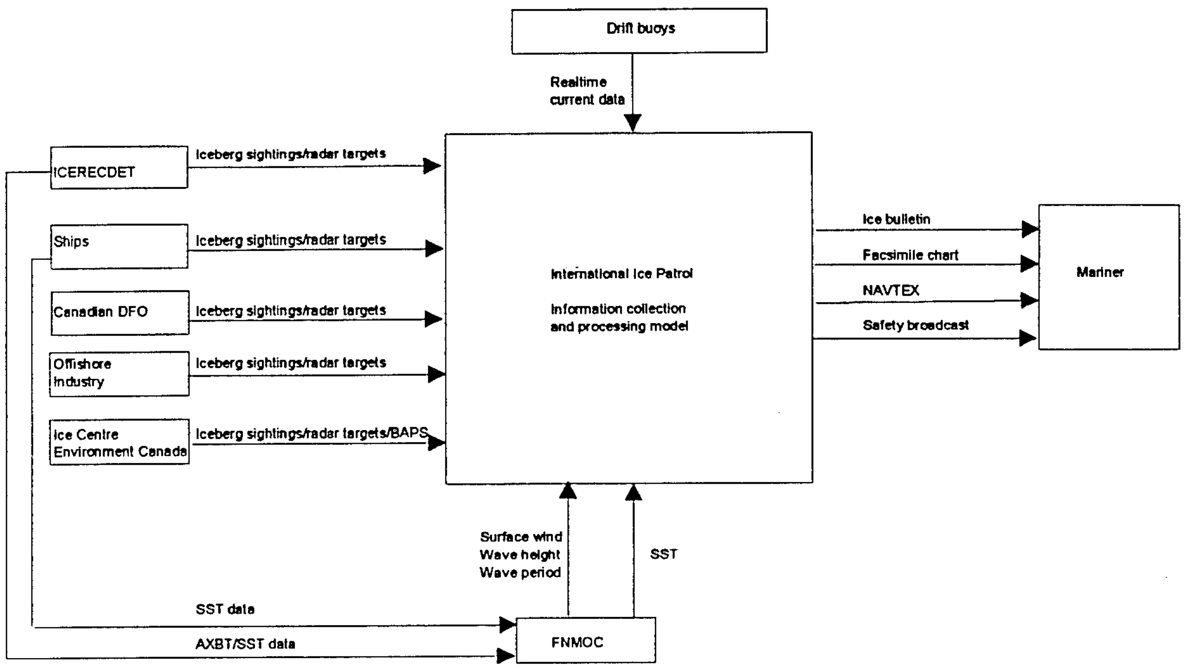

Figure 1. IIP Information Processing Context Diagram.

The key data inputs are the iceberg and radar target sightings/reports, and selected environmental data which permit iceberg drift and deterioration to be modeled. The drift and deterioration models and the policies/parameters associated with their operation combine to provide prognosis (predicted) positions of icebergs which determine the LAKI.

The IIP effectively captures available data on iceberg and radar target sightings from other organizations as well as from IIP Ice Reconnaissance Detachment flights. Sighting statistics are indicated in Table 1. Over 60% of these "sightings" are radar based and less than 40% are visual sightings. Nearly three-fourths of the visual sightings are received from ships operating in the area.

Because of the importance of high quality information along the Limits of All Known Ice, the IIP deploys an Ice Reconnaissance Detachment (ICERECDET) from St. John's, Newfoundland to conduct surveillance flights that concentrate on providing information on icebergs and radar targets in the area defining the LAKI. The primary surveillance device is the AN/APS-135 SLAR augmented with the AN/APS-137 FLAR mounted on an HC-130H aircraft. The AN/APS-135 SLAR radar will reach technological obsolescence (dry film processor) in the 1996 season. Present aircraft assignments effectively limit searches of particular geographic regions to once every two weeks.

Table 1: Iceberg and Radar Target Sightings Entered into IIP Models, 1988-1994.

	1988	1989	1990	1991	1992	1993	1994
IIP	854	1039	1140	1503	685	1056	1066
Other Air	131	269	408	393	1493	3908	3407
AES	638	256	136	192	159	1031	1817
Ships	501	873	1287	2237	745	1475	1845
BAPS	0	205	4	0	82	556	1311
DOD	15	256	171	35	3	0	0
Other	47	91	10	9	3	32	0
Total	2186	2986	3156	4370	3170	8058	9446

A major argument for the reduced frequency of ICERECDET patrols since 1983 is the availability of all-weather detection capability with the SLAR and the use of the iceberg drift and the iceberg deterioration models. While these models appear to be conceptually sound, they depend heavily on environmental data and iceberg characteristics that may have significant estimation errors. The primary source of environmental data is the U.S. Navy Fleet Numerical Meteorology and Oceanography Center (FNMOC). IIP receives surface wind, wave height, and wave period data twice a day and sea surface temperature (SST) data once each day. In addition, realtime current data from IIP deployed drift buoys is incorporated on a regular basis to temporarily modify the (geostrophic) Labrador Current data file. The surface wind, iceberg position, estimated iceberg size, and geostrophic current are used in the iceberg drift model. A separate iceberg deterioration model uses the iceberg position, iceberg size, SST, and wave height and period data. Limited experiments to validate the models have been conducted. The results suggested that the models are reasonable representations, but errors are likely associated with input data accuracy. The initial analysis concluded that before any significant expense be incurred to identify/acquire higher quality environmental data, a sensitivity analysis of the models should be conducted along with an examination of the model interaction, including the effects of resights.

The initial analysis (Annex A) concluded that the IIP operation is well managed. Fairly detailed procedures are established and documented. Personnel are well-trained and knowledgeable. The new (2 years) computer system greatly facilitates the processing of data. The electronic file interchange procedures in use permit effective quality assurance checks of input data. The major equipment deficiency is the processor speed on the main

computer system. Personnel levels recently have been reduced to allowance levels. This appears to be adequate for continued operation, although there is little room for personnel vacancies. The estimated cost of the IIP operation for 1993 billed to the contributing governments was $3.245M. Costs are driven primarily by the ICERECDET which accounts for nearly 75% of the total cost. It is not known whether all billed costs have been recovered. In addition, it is not clear that all operating and support costs for the program have been identified and included in the billed amount. [Resolved in Annex D.]

The critical factor which is well known, but confirmed by the initial detailed review of current IIP operations, is the role of detection. Much of the effort in the IIP has been to compensate for the deficiency in detection by means of models of iceberg drift and deterioration. Primary emphasis in the present analysis is on identifying alternative means of detecting, identifying, and classifying icebergs. Unless that can be done on a continuous basis, some prediction capability will be required. Although a key assumption at the kick-off meeting was that the Coast Guard will continue to manage and conduct the Ice Patrol, other possible management arrangements should be considered as alternatives. Part of the analysis should further review the proposed program performance measures of effectiveness.

3.0 Assumptions, Criteria, and Alternatives.

3.1 Classification of Alternatives.

In developing alternatives, it will be more efficient to decompose the alternatives in the form suggested in the study proposal and modified in the analysis of current operations. In particular, there are four levels or categories of alternatives as follows:

Management alternatives. This category includes various approaches to managing the IIP. Alternatives to be developed may include continued Coast Guard management or active management by another country for example.

Modeling alternatives. This category includes various approaches to modeling iceberg movement and deterioration. Also included are alternative assumptions/policies/ procedures that drive the models and affect their interaction.

Data acquisition/processing alternatives. This category includes alternative approaches for acquiring sighting and environmental data with requisite levels of accuracy and precision. It also includes alternative methods and organizations for processing that data and exercising any models.

Surveillance/detection/classification alternatives. This category includes various alternatives (platforms and sensors) for conducting surveillance and detecting and classifying icebergs. The scope of alternatives extends from equipment to be used to alternative organizations for conducting the activity.

If there were three alternatives in each of these four categories, they could be combined to form 81 separate alternatives to be evaluated. As will be seen, not all such combinations would make sense. For example, Canadian management of the IIP would most likely result in Canadian data acquisition/processing and Canadian surveillance and eliminate other alternatives in the latter categories. Considering the categories separately eliminates the need to consider all possible combinations. The resulting evaluations at the category level will permit meaningful combinations to be formed. The specific alternatives in each of the four categories are developed in the following sections.

3.2 Analysis and Planning Assumptions.

In developing potential alternatives, we were guided by the assumptions and guidelines developed at the contract kick off meeting. The major assumptions included:

① Only consider proven technology. IIP will not develop new technology.

② The primary focus of the IIP is on identifying the LAKI. The only interest in obtaining better iceberg position/identification information inside the LAKI is with regard to improving the ability to describe the LAKI.

③ IIP will remain under Coast Guard control. At the Alternative Selection Meeting, this assumption was relaxed to allow alternatives that included broader management options.

3.3 Evaluation Criteria for Selecting Alternatives for COEA.

Selection of alternatives for the detailed cost and operational effectiveness analysis was the responsibility of the Program Manager. An evaluation and selection meeting was held on October 14, 1994 at the IIP Headquarters, Groton, CT. The meeting convened at 0830 and completed its review by 1300. Various staff and IIP personnel provided suggestions and guidance as alternatives were developed and discussed. Attendees are listed in Table 2.

Three general criteria were used to guide the evaluation.

① Technical feasibility was required for each alternative. This is a slightly weaker requirement than "proven technology."

② It was required that there be a reasonable likelihood that the alternative would be able to accomplish the mission objective. Some alternatives would be stronger than others with regard to this criterion.

③ Alternatives must be available at reasonable cost. Detailed cost estimates were not developed for some alternatives. In some cases, cost estimates could clearly indicate that it was cost infeasible.

Table 2: Participants in Alternatives Selection Meeting, October 14, 1994.

Attendee	*Organization*
CAPT Alan Summy	Chief, Ice Operations Division (G-NIO)
Larry Jendro	Chief, Science Branch (G-NIO-3)
CDR Ross L. Tuxhorn	Commander, International Ice Patrol
LCDR Bruce E. Viekman	Deputy Commander, IIP
Donald L. Murphy	Chief Scientist, IIP
LT Geoffrey A. Trivers	Ice Patrol Officer, IIP
LT Robert T. Haines	Science Officer, IIP
MSTC John Fisher	Senior Ice Observer, International Ice Patrol
CDR John W. Schoen	Operations Officer, AIRSTA Elizabeth City
CWO Bob Vessey	AIRSTA Elizabeth City
CWO2 Brad Smith	Commandant (G-EAE)
Clark Pritchett	CGR&DC, Project Manager
Dr. Marc Mandler	CGR&DC, Systems Analysis Branch Chief
LT Chris Rodriguez	CGR&DC, Systems Analysis Branch
Dr. Robert L. Armacost	EER Systems/University of Central Florida

4.0 Management Alternatives.

4.1 Existing Management Structures.

Under provisions of SOLAS 74, Chapter V, Regulations 5-8 the SOLAS treaty, the United States is the Managing Government for the IIP. Day to day management responsibility is assigned to the U.S. Coast Guard as provided by 46 USC 738, 783(a)-(d). Commander, International Ice Patrol, located at Groton, CT operates under the operational control of Commander, Atlantic Area. The Program Manager is the Chief, Ice Operations Division, Commandant (G-NIO), at Coast Guard Headquarters. Program support is provided by the Aeronautical Engineering Division (G-EAE) and the Aviation Division (G-OAV). Aircraft operations are conducted by Coast Guard Air Station Elizabeth City, NC.

The FY93 operating budget for CIIP was $224,666. The allocated program cost developed by Commandant (G-CFM) for FY 93 was $3,245,300. This latter amount is the amount billed to the Contributing Governments (the 17 governments that have agreed to reimburse the U.S. for the operating cost of the IIP). The FY 93 cost includes a prorated IIP personnel cost covering only that portion of the year during which the IIP was issuing ice bulletins. In the future, the entire year cost of the IIP personnel will be

included. It is not clear whether all costs associated with the IIP have been included. Detailed costing of current operations is a Phase II task.

4.2 Development of Management Alternatives.

Management alternatives represent options that will take full responsibility for the conduct of the IIP mission. Several alternatives are discussed in detail below. Two of the alternatives (Canadian management and National Ice Center management) were developed at the Selection meeting when the CG control assumption was relaxed. No cost estimates are available for any of the alternatives at this time.

4.2.1 *Canadian management.* The first alternative is to have the Canadian government assume the role of Managing Government under SOLAS 74. This option would necessarily require an amendment to the treaty. An overview of the current Canadian operations and the potential for Canada assuming this management role is contained in Appendix A. The existing infrastructure in the AES Ice Services is fully capable of taking on the mission of the IIP. However, all Canadian governmental units are under strong pressures to reduce budgets. Absent any political motivation, it is unlikely that Canada would be willing to take on the full responsibility for the IIP without a strong guarantee of full reimbursement of the operating costs. A potentially viable alternative would be for the U.S. (perhaps through the Coast Guard) to contract with Canada to manage the entire IIP mission.

4.2.2 *National Ice Center management.* In the past, the National Ice Center has been very interested in having the IIP responsibility shifted to its control. It is believed that the assumption was that the Coast Guard resources (e.g., personnel, aircraft support) would be included in such a shift. A change in responsibility to the NIC would require a change in the USC, but would not require an amendment to SOLAS because the U.S. would remain as the Managing Government. There is no apparent advantage to moving the responsibility to the NIC if the Coast Guard is still responsible for providing the resources and conducting the IIP mission. A potentially viable alternative is for the NIC to assume full responsibility for conducting the IIP including the funding of all operations.

4.2.3 *Private management under CG direction.* Another alternative is to have a private firm manage the IIP mission under Coast Guard direction/supervision. The intent is that the private firm would provide or contract for all services and functions required to meet performance specifications developed by the Coast Guard. With the exception of some communications functions, no Coast Guard resources such as ships, aircraft, and personnel that have traditionally been used for IIP functions would be provided.

4.3 Selected Management Alternatives.

Based on a discussion of the various alternatives and considering the evaluation criteria, the following three alternatives were selected:

① U.S. management with Coast Guard assigned responsibility (current system).

② Canadian management. Because of the need to amend SOLAS to incorporate this alternative, it will be approached as U.S. management (Coast Guard) with all work contracted to Canada..

③ U.S. management with National Ice Center assigned responsibility. This alternative assumes that NIC will assume all IIP functions.

4.4 Miscellaneous Management Issues.

Measuring the effectiveness of the IIP program is an ongoing concern. In 1993, a user survey was distributed. Limited response provides a high level of satisfaction with IIP performance. It would be beneficial to obtain a larger response. It was agreed that Phase II should include a minor effort to conduct a user satisfaction survey. Several alternative mechanisms will be explored to determine a cost-effective way of conducting the survey. Survey items will be developed in conjunction with the Program Manager and CIIP.

5.0 Modeling Alternatives.

5.1 Overview of Existing Models

The IIP iceberg drift model moves icebergs through the IIP operation area while the iceberg deterioration model melts the icebergs over time until it is considered safe to remove a particular iceberg from the IIP plot and cease active tracking and reporting. In addition to iceberg position and size data, both of IIP's models require substantial environmental input data. Accuracy of the input data obviously affects the accuracy of the predicted positions and sizes of the icebergs. The drift and deterioration models are incorporated in the Data Management and Prediction System. Various policies such as assumed size for unclassified icebergs, resight procedures, and deletion policies impact the results provided by the models. The models were described in detail in the Interim Report on the Analysis of Current Operations of the IIP. Summary descriptions are provided below.

5.2 Iceberg Drift Model

5.2.1 *Basic model and input data.* The iceberg drift model used by IIP was completed and tested in 1980 (Mountain, 1980). Its format and use remains essentially the same to date. The fundamental drift model balance is between iceberg acceleration, air and water drag, the Coriolis acceleration and a sea surface slope term which describes the mean ocean currents. The resulting differential equations are solved using a fourth-order Runge-Kutta analysis. Key input data include: iceberg location; iceberg size and shape; local wind; geostrophic (mean) current; and local currents from drift buoys.

Sensed or sighted icebergs are placed into one of four size categories (growler, small, medium, and large with no upper limit) which also automatically sets the mass and cross-sectional areas to the assumed characteristic values for the designated size category. One of two specific shape classifications, tabular or non-tabular, is also made when a visual sighting occurs. The model divides the subsurface shape of the iceberg into four draft layers, each with its own cross sectional size. These areas are affected by the geostrophic ocean water current and a calculated depth and time dependent local wind driven current. Icebergs whose size are unknown are assumed to be medium icebergs; those whose shape are unknown are assumed to be non-tabular icebergs. The model is operated every 12 hours using the most recent wind data, and drifts all icebergs on plot within the IIP operations area.

5.2.2 *Model assumptions.* The IIP estimates that the initial position error is 5 nm regardless of sighting source and that model drift error increases linearly in 5 nautical mile per day increments for each 24 hours of additional model drift up to a maximum radius of 30 nautical miles. This maximum error of 30 nautical miles occurs after 5 days of drift. There is no increase in the maximum 30 nautical mile error estimate regardless of how long the iceberg is drifted within the IIP operations area. If an iceberg is resighted, the drift error calculation is restarted. Icebergs south of 40°N are assumed to have a daily drift error of 10 nm, accumulating over a period of 5 days to a maximum error of 55 nm.

5.2.3 *Model validation.* Initial model tests in 1980 used the tracks of 2 large tabular icebergs, a large pinnacle iceberg, and a freely drifting satellite-tracked buoy (Mountain, 1980). Results ranged from approximately a 5 nautical mile error for a 3 day drift to a constant 50-80 nautical mile error in the 25 day case. The assumed cause for the error in this test was stated to be inaccurate wind and current data inputs to the model.

In 1985, drift model tests were held in several different parts of the IIP operations area (Murphy and Anderson, 1985). Four case studies were performed using the drift model. In 3 of the 4 cases, the drift of the icebergs as depicted by the model using the system data had location errors ranging from 40 nautical miles after a 2.5 day drift, 30 nautical miles after a 3.3 day drift, and 45 nautical miles after a 4 day drift. These all exceed the standard drift error assumed by the IIP of a maximum of 30 nautical miles after a drift of 5 days. The 4th case study drift did remain well within the standard drift error and did not exceed an error of more than approximately 11 nautical miles over a 4 day drift. Better performance results from the model were realized when using the observed current and wind data for all four case studies, instead of the automatically provided system data. However, in only one case was the predicted iceberg drift position error well within the accepted limits. Projecting a drift experiment such as this for a total period of 2 weeks, or 3 times as long as these case studies, suggests that the drift errors would continue to generate and become even larger.

5.2.4 *Evaluation.* Using the on scene wind and current data resulted in estimated positions closer to the actual iceberg position than using geostrophic currents

and FNMOC winds. The experiments suggest that the structure of the model is sound and that its accuracy depends on the accuracy of the input data. The experiments did not isolate wind or current as the primary causal factor in generating errors. However, one case in Murphy and Anderson (1985) showed significant improvement by using observed currents with FNMOC winds. It should be noted that three of the cases in the Murphy and Anderson (1985) experiment were located in areas where significant reductions in geostrophic currents were instituted in 1989-90 (Murphy, Hanson, and Tuxhorn, 1990). It is also important to note that based on the trends in the various drift results, if the tests were continued beyond the 4 days, the model error would exceed, if not greatly exceed the 30 nautical miles maximum drift error after a period of 10 days of predictions even with using the best on scene, observed data available. In practice, it is not known to what extent positional errors affect the overall accuracy of the predicted positions.

5.3 Iceberg Deterioration Model

5.3.1 *Basic model and input data.* The iceberg deterioration model used by IIP was completed and initially tested in 1983 (Anderson, 1983). This model was based on the work of White, Spaulding, and Gominho (1980). The model considers four forms of deterioration: insolation (sun heating), buoyant convection (vertical circulation of the water), wind forced convection (drift movement through the water), and wave induced (wave washing of the subaerial surface). Four equations determine the melt due to each of these processes which are additive. Note that the model does not account for deterioration due to calving. Input data include: iceberg position; iceberg size; sea surface temperature; wave height; and wave period. Progressive deterioration of the iceberg is quantified by its waterline "length" by definition. There are four size categories: growler, small, medium, and large with no upper limit. The model used by IIP does not include deterioration due to calving of overhanging ice slabs (El-Tahan, Venkatesh, and El-Tahan, 1987). Deterioration due to calving depends on the thickness of the overhanging slab which is not generally available. Not including deterioration due to calving underestimates the degree of deterioration in a given time period.

5.3.2 *Model assumptions.* The model initially uses the maximum waterline length for the size category reported. If an iceberg is resighted, the waterline length is set to the maximum for the size reported in the resighting eliminating any deterioration which may have occurred if the resighting indicates the same or larger size. Icebergs for which no size category is reported are assumed to be medium icebergs. Icebergs are removed from the model when 125 percent of their original waterline length has been melted if they remain within the LAKI, unless they are limit setting icebergs in which case they are retained by the deterioration model until 150 percent of their waterline length has been melted.

5.3.3 *Model validation.* A mathematical analysis of the model, with all other parameters held constant, showed that a 100 meter iceberg length took 179 days to melt in -1°C water compared with 20.5 days in 3°C water (Anderson, 1983). Thus, input data errors of 1°C variance from actual sea surface temperatures in this temperature range can

produce melt errors on the order of 40 days for this 100 meter berg length. These results suggest that sea surface temperatures are the most critical parameter. However, other parameters were not examined and the results only hold in the range of SST considered in the analysis.

Several studies by Venkatesh, El-Tahan, and Mitten (1985), Venkatesh (1986), and El-Tahan, Venkatesh, and El-Tahan (1987) compared model performance with observed deterioration of several icebergs using observed oceanographic and meteorological data. They also developed refined size estimates. Using these data, they found good agreement between the model results and actual deterioration.

In 1987 the IIP conducted a deterioration study using 6 icebergs, observed and tracked by a surface vessel (Hanson, 1987). The time of observation on each iceberg ranged from 2.1 days to 6.3 days. The objectives of this study were to compare iceberg deterioration predictions derived from observed environmental to predictions using system (FNMOC) data. FNMOC SST data were an average of 1.3 degrees C colder than that actually observed, the wave heights averaged 0.9 meters higher than observed, and the periods were on average 4.6 seconds greater than observed. The 6 iceberg cluster averaged 379 cm/day melt rate of their waterline length using observed wave erosion values, while using the operational data provided by the Navy produced a melt rate on average of 531 cm/day. The overestimation of the predicted wave height was identified as the primary cause of the significant overestimation of the melt rate, even though the predicted temperatures also averaged 1.3 degrees C colder, which would tend to slow the melt rate. The actual observed iceberg length changes as compared with the model predictions made as part of this test were inconclusive due to the time constraints, (i.e., 2 to 6 days.)

5.3.4 *Evaluation.* The various studies suggest that the iceberg deterioration model is a reasonable approximation of the deterioration process when observed environmental data is used, although no iceberg has been observed to the point of 100% melt. The 1987 IIP study identified significant differences between the FNMOC data and observed data. In 1988, all FNMOC environmental products were improved and the new data was used by IIP (Hanson, 1988). The new values for SST, sea height, and sea period are reportedly in agreement with observed values, although no validation experiments have been reported. None of the IIP analyses or reports indicates that a complete sensitivity analysis of the deterioration model has been conducted. In particular, sensitivity of wave height estimates and their interaction with the initial size estimate requires further exploration.

5.4 Model Interaction, Assumptions, and Use

All evaluations of the drift and deterioration models have been conducted separately. In practice, the two models form part of a larger analysis model that is used to estimate the LAKI. The operation of the two models, along with other assumptions, policies, and procedures, and with the variance introduced by different watch officers

forms an operating system that has not been evaluated as a whole. For example, it is not clear that the size estimates used in the drift and deterioration models are compatible. The drift model assumes that the size is constant within a given category and that deterioration has no effect on drift until a smaller size category is reached. The guidelines for resights require the distance between a new sighting and a predicted iceberg position to be less than twice the system error, assumed to be 60 nm. However, a new sighting should have a positional error of 5 nm and the maximum error for a predicted iceberg position is 30 nm, and, hence, the maximum distance for a resight should be 35 nm. With the existing models, there is no basis for estimating any confidence levels associated with particular actions or specifications of the LAKI. Current procedures exercise the drift and deterioration models for the "analysis" runs which incorporate all available information to date. The LAKI are determined based on "prognosis" in which only drift is considered and additional deterioration in the 6-24 hour period covered by the prognosis run is ignored. The impact of including deterioration in that period should be considered.

5.5 Sensitivity Analysis

To illustrate the impact of potential data errors, a preliminary sensitivity analysis for the iceberg deterioration model is included in Appendix C. The results demonstrate that in general, SST was the parameter to which melt was most sensitive, except at low values of SST where wave height was dominant. Of all parameters, the size classification had the greatest effect. The IIP assumed error of ±1 size category could result in significant errors. There has been no comparable analysis of the drift model. It is also important to note that there has been no examination of the sensitivity of the model results to positional errors. In some locations, a positional error of 10 miles could mean a significant difference in geostrophic current values and may impact SST and local wind estimates. Thus, if the models react to wrong influences, errors in predicted locations and size compound.

5.6 Development of Modeling Alternatives

5.6.1 *Major revision to existing models.* A clear alternative is to establish a major research effort to develop new drift and deterioration models. At this point, alternative models that are implementable with reasonably available input data do not appear to exist. This alternative fails the "proven technology" criterion. Moreover, the various studies discussed in detail above do support the reasonableness of the iceberg drift and deterioration models as approximating actual iceberg behavior.

5.6.2 *Improve input data.* All of the model evaluations suggest the need for better input data. However, there have been a number of modifications to the generation of the input data since those evaluations. In particular, FNMOC improved the wind, SST, sea height, and sea period inputs in 1988. In 1989-90, IIP modified the geostrophic current data base using observed data from drift buoys. This resulted in a significant reduction in current velocity estimates in a number of critical areas. To date, it is unknown how well these adjustments have caused the system data to more accurately

reflect actual data. Further improvement in current estimates may be possible by the use of *objective analysis modeling* being developed by Applied Mathematics, Inc. through the CG R&DC for the SAR program. Objective analysis modeling involve using limited, sparse, or non-uniformly distributed oceanic data sets of either scalar or vector quantities, and providing a best estimate of how these may fit into a more uniform, gridded data field. The analysis also provides an estimate of the error of the fit.

Input data could be improved by using new means of collecting the critical data and using it directly in the model. Increased use of drift buoys and other devices for providing real time SST, local wind, and wave height/period data could be developed and deployed. However, there is no basis for concluding that such efforts would improve the forecasting without a better understanding of the entire system.

5.6.3 *Probabilistic model.* The existing models depend on having estimated positions of the icebergs and then drift/deteriorate them over time so that some become the "extreme" icebergs and define the LAKI. Dr. Alan Washburn at the Naval Postgraduate School is currently engaged in a project to develop probability distributions that would characterize iceberg densities over the area normally enclosed by the LAKI. Such a model could be used to generate icebergs on a probabilistic basis that would then be drifted and ultimately determine the LAKI with some stated probability. The base document would be the equivalent of a probabilistic Atlas of Icebergs.

5.6.4 *Integrated risk analysis.* A final alternative is to conduct a comprehensive sensitivity analysis of the system of models that is used to generate the LAKI. Such an approach requires a clear identification of the various data inputs as well as policies and assumptions, and the way that each influences other elements of the system. This analysis would evaluate the error propagation throughout the system and ultimately lead to the ability to characterize the risk associated with the model. This analysis should lead to identifying areas of potential refinement or improvement of the existing models, and should identify the need for areas of validation of these models.

5.7 Selected Modeling Alternatives

Based on the above analysis and discussion at the Alternatives Selection Meeting, Phase II should focus on conducting a detailed sensitivity analysis of the system and develop an approach to characterize the risk posture for the IIP. If this analysis identifies particular problems with specific data inputs, alternative methods of acquiring more reliable data should be evaluated. In general, data improvements will be evolutionary and it is likely that input data will be obtained from major models such as those provided by FNMOC and similar agencies. The iceberg density model being developed by Dr. Washburn could be integrated with such an analysis to improve the confidence in the estimates, but reliance on a probabilistic Atlas of Icebergs, even modified for general weather conditions, seems to be a step sideways. At this point, a major revision to the existing models is considered unnecessary.

6.0 Data Acquisition/Processing Alternatives.

6.1 Existing Data Acquisition and Processing Procedures

6.1.1 *Data acquisition.* Model system input data is obtained from a number of sources in various forms that require different levels of processing. All environmental data is received in digital form from FNMOC via Internet. All iceberg sighting data received from ICEC, including BAPS data, AES surveillance, Atlantic Airways surveillance, and ship sighting reports submitted to ICEC, are transmitted to IIP in digital form via Internet. Ship sighting reports submitted directly to IIP must be coded in order to be used in DMPS. The most labor intensive aspect of data acquisition is sighting data obtained on ICERECDET flights. The approximate positions of iceberg/radar target sightings are transferred from the SLAR dry film to a message format which is sent as a digital file to IIP. The sighting positions are estimated from the INS position of the aircraft. Error sources include INS error, which varies as the flight progresses, and the estimation error in transcribing from the dry film. This error will be significantly reduced when the Global Positioning System (GPS) capability is added to the Coast Guard surveillance aircraft.

6.1.2 *Data processing.* Current data processing only requires a capability for handling manual or digital data. No georeferenced images are received and no processing capability exists at IIP to analyze such images. Incoming messages are processed for quality assurance using separate PCs before transferring the files to the DMPS. The DMPS is installed on an INTERGRAPH modified VAX computer system that was initially developed for ICEC. IIP began full use of this system in the 1993 season. The system is very functional but processing times are relatively slow and delays are encountered when processing large files. An updated system is planned in the Commandant's 1996 IRM plan. The existing system uses a geographic base map on which various data files can be overlayed for comparison and analysis purposes. Iceberg information such as location, size, shape, melt state, and track is displayed graphically using symbols and colors.

6.2 Development of Data Acquisition Alternatives

Data acquisition alternatives assume that the Coast Guard will continue to operate the IIP and process the data.

6.2.1 *Digital based manual data collection and transmission.* This alternative essentially continues the existing system. It may be modified for ICERECDET sighting information as the existing AN/APS-135 SLAR is replaced.

6.2.2 *Digital acquisition of surveillance data.* Atlantic Airways Limited has developed an Airborne Data Acquisition & Management System (ADAM) which automates the tasks associated with airborne data collection. The ADAM system is a real time data acquisition and management system that graphically displays spatially distributed objects on a Mercator projection chart. Aircraft position information and object position

information obtained by digitally processing radar displays are integrated on a real time display. The ADAM system provides iceberg charts and prepares digital files in MANICE format. Commandant (G-EAE) has developed a similar system for Marine Environmental Protection activities and has a prototype system operating on a 486 portable computer. The prototype accepts navigational input, including GPS data, and object data entered by the operator.

6.2.3 *Remotely sensed image acquisition.* If it is determined that some remotely sensed images are to be used in the analysis, it will be necessary to develop a capability to acquire such images. Such images could range from satellite images (e.g., NOAA, ERS-1, RADARSAT) to radar images. Under the alternatives presented above, information is extracted from the display and recorded digitally. The image is lost to further analysis.

6.2.4 *Real time data acquisition/transmission.* Real time data acquisition and transmission requires the availability of accessible communications links. This alternative applies to ICERECDET data. Iceberg sightings outside of the LAKI are reported immediately to IIP by message. The current system provides all of the flight data immediately following the aircraft return. This procedure is timely and there does not appear to be any significant advantage to providing real time data.

6.2.5 *Automated flight path planning.* This alternative assumes that digital acquisition of surveillance data is incorporated along with the use of GPS for navigation. The alternative involves developing an algorithm to optimize the probability of detection of icebergs by setting the flight path relative to the surface wind.

6.3 Development of Data Processing Alternatives

6.3.1 *INTERGRAPH system with DMPS.* The existing INTERGRAPH system functions well as indicated in section 6.1.2. The system will be upgraded or replaced in the near future, and INTERGRAPH is prepared to upgrade the existing system. A major advantage of the existing system is the parallel operation with ICEC. Most of the enhancements to the existing system have been developed and funded by ICEC with no cost to IIP. Continued use of the INTERGRAPH system will preclude the use of remotely sensed images for direct analysis. The ICEC will be abandoning this system in 1996 as described below. This alternative to maintain the use of the INTERGRAPH system for DMPS will require the IIP to take primary responsibility for maintaining the system.

6.3.2 *ISIS system.* The ICEC has a current project to develop an Ice Services Integrated System (ISIS) which will facilitate processing of multiple images. A conceptual overview of the project is included in Appendix B. The proposed system will fully integrate the satellite image processing, SAR/SLAR aircraft imagery, and all environmental data on a geocoded/ georeferenced basis. ICEC will standardize on HP 9000 workstations for this system. Under their development plan, BAPS (DMPS) will be integrated into the system by the end of 1996. Implementation of such a system at IIP

would provide a capability for using remotely sensed images. If images from RADARSAT would be effective in identifying icebergs, such a capability would be required. Actual use of such images would impact the personnel qualifications and training requirements and create a new analysis infrastructure.

6.3.3 *Contracted data processing.* A third alternative is to contract with a third party (e.g., commercial firm, ICEC) to process data. Unfortunately, data processing within DMPS is an interactive process, requiring decisions at various points in the analysis. A major source of input judgment occurs in the resight and deletion analysis. Contracted data processing would be difficult to oversee by the Coast Guard.

6.3.4 *DMPS on a new operating system.* A final alternative is to install DMPS on another graphics based operating system.

6.4 Selected Data Acquisition and Processing Alternatives

6.4.1 *Data acquisition alternatives.* The availability of ADAM or a system with similar capability makes this alternative one that should be considered in Phase II. It was concluded that real time data transmission is not required and need not be examined further. Similarly, there is no current need for acquisition of remotely sensed images. Although automated flight path planning may be valuable, it is not of high enough priority to be included in the Phase II COEA.

6.4.2 *Data processing alternatives.* The selected alternatives are to examine the upgrade of the INTERGRAPH system and the switch to the ISIS system when its development is completed. The examination of these alternatives is intended to be a general comparison, not a detailed system design.

7.0 Surveillance/Detection/Classification Alternatives.

7.1 Existing Surveillance/Detection/Classification Modes

7.1.1 *Sources.* The IIP uses numerous sources of iceberg sightings and reported radar targets. The total sightings for the 1984-1994 period are included in Table 1 by source. Primary sources include ships transiting the area, icebergs drifting into the area through 52°N as tracked by ICEC (BAPS), sightings by AES aircraft, sightings by Atlantic Airways aircraft, and sightings by ICERECDET aircraft.

Icebergs either drift south of 48°N or are sighted south of 48°N. Of the 7915 icebergs/radar targets entered into IIP models (from Table 1), 1660 were recorded south of 48°N. Table 3 provides some basis for identifying the current efforts supporting iceberg detection.

Table 3: Source of Icebergs S of 48°N, 1994.

1994	IIP	Other Air	AES	Ships	BAPS	Total
Drifted S of 48°N	45	143	164	84	24	460
Sighted S of 48°N	244	524	180	357	0	1305
Total	289	667	344	411	24	1765

IIP was responsible for detecting 16%, Atlantic Air detected 37%, AES detected 21%, and ships detected 18% of the icebergs. Although the IIP was responsible for the smallest percentage, the particular icebergs were generally the ones of greatest importance --those in the vicinity of the LAKI.

Ships transiting the area are requested to report the positions of ice and icebergs to CIIP or ICEC. Their sightings may be visual or radar. The observer's experience greatly affects the quality of the information provided.

ICEC employs two ice reconnaissance aircraft. A Dash-7 turboprop normally is used on the east coast of Newfoundland operating near the sea ice edge. It is equipped with side and top bubbles for visual observation and a real aperture CAL SLAR. The aircraft is owned by Transport Canada and operated under contract with Bradley Air Services, Inc. Three Environment Canada Ice Services Specialists staff the aircraft. The second aircraft is a Challenger jet provided under contract with Intera Technologies, Ltd. It is equipped with two MacDonald-Dettwiler IRIS SARs imaging a 100 km swath on each side of the aircraft. It is staffed completely with Intera personnel. Both aircraft have a downlink system that allows in-flight transmission of digital radar imagery.

Atlantic Airways conducts aerial reconnaissance of the fishing fleet on the Grand Banks under contract to the Canadian Department of Fisheries and Oceans. At times, it also performs surveillance flights directly for the ICEC. In addition to visual observation capability, the aircraft is equipped with a Litton APS-504(V)5 search radar that provides significant coverage of ice in their area of observation. In 1992-1993, Atlantic Airways was the largest contributor of sightings to the IIP.

7.1.2 *IIP ICERECDET.* The IIP ICERECDET presently uses a HC-130H aircraft equipped with a pair of Motorola AN/APS-135 Side Looking Airborne Radars (SLARs) (two antennas mounted in pods on either side of the fuselage, with common signal processing) and one nose-mounted Texas Instruments AN/APS-137(V) Forward Looking Airborne Radar (FLAR). Observation windows allow visual observation of icebergs. The ICERECDET deploys from St. John's, Newfoundland. In the past, the ICERECDET has used an HU-25B aircraft with the AN/APS-131 SLAR is installed as part of the AIREYE system. The AN/APS 131 is very similar to the An/APS 135. However, its antenna length is half of the length of the AN/APS-135 (2.4 m v. 4.8 m) with the result that it has a lower azimuth resolution (0.8° v. 0.47°). In a side by side operational comparison, Alfultis and Osmer (1989) concluded that the AN/APS-131

SLAR installed on the HU-25B was nearly as effective as the AN/APS-135 SLAR when appropriate operating parameters were used.

The technical characteristics and performance of the AN/APS-135 SLAR and the AN/APS-137 FLAR systems were discussed in detail in the Interim Report on the Analysis of Current Operations of the IIP and are not repeated here. Recent experience with using the two systems together suggest that the combination provides a higher likelihood of correct classification of radar targets. The combined effect of using the two radars has not been analyzed in detail. The AN/APS-135 SLAR reaches technological obsolescence in 1996. In addition to technological obsolescence, there is an upcoming support obsolescence as well. Many of the individuals who maintain and operate this radar are nearing the end of their service careers. Because of its one of a kind nature, all training is on the job and there is no factory maintenance support for the radar. A FY96 RCP provides for upgrading the AN/APS-135 SLAR with a digital porcessor.

7.1.3 *Procedures/policies/assumptions.* Certain aspects of surveillance and detection operations are embedded in the data acquisition, processing, and modeling aspects presented above. However, several policies impact the probability of detection and classification of icebergs. One such policy/procedure is the selection of the search pattern and coverage factor. Patrols are conducted using a Papa Sierra parallel search pattern with a track spacing of 25 nm. The SLAR range scale is set at 27 nm so that the SLAR coverage is nearly 200%. The purpose of the 200% coverage is to try to ensure that small icebergs and growlers are detected and to provide a means of determining target movement and aid in identification of a radar target as an iceberg. The track spacing and SLAR characteristics result in almost one-third of the search area having a 100% coverage rather than 200% coverage and no opportunity for the SLAR operator to assess target motion and assist in identification of icebergs. There appears to be no recorded analysis of the probabilities of detection over the search area. This assessment is important for determining the risks associated with the current search procedure.

Current policies classify sightings by sources other than ICERECDET as radar targets unless visually identified as icebergs. The ICERECDET SIO has the authority to classify radar targets as icebergs based on the characteristics of the radar image and other factors.

7.2 Overview of Alternative Methods

Reliable detection, identification, and classification of icebergs is the heart of the IIP analysis. The IIP has incorporated new technology over the years to improve its ability to identify the LAKI accurately. The combination of improved detection technology with modeling efforts has served to control the program costs while simultaneously providing highly reliable information to the mariner. Advances in detection technology present an opportunity for further improving the program.

Technological approaches to improved detection include the use of satellite systems, various ground based systems, and unmanned and manned airborne systems. The most promising alternatives continue to be the latter systems. Various alternatives are presented in the following sections.

7.3 Satellite Technology Alternatives

Satellite alternatives focused on those alternatives which satisfied the proven technology criterion and were accessible. There is no indication that restricted access satellite systems exist that would provide the all weather resolution necessary to detect icebergs.

7.3.1 *RADARSAT.* RADARSAT, now scheduled for launch in mid-late 1995, will be operated by the Canadian Space Agency. The intended use of RADARSAT is discussed in Appendix A. It will provide all weather coverage of the Canadian ice covered waters to facilitate ice forecasting for shipping. RADARSAT has eight imaging modes. ICEC intends to primarily use the ScanSAR(Wide) mode with a swath width of 500 km and resolution of 100m. The finest resolution of 12x9 m is provided by the Fine Res mode with a 45 km swath width. The various modes are illustrated in Figure 2.

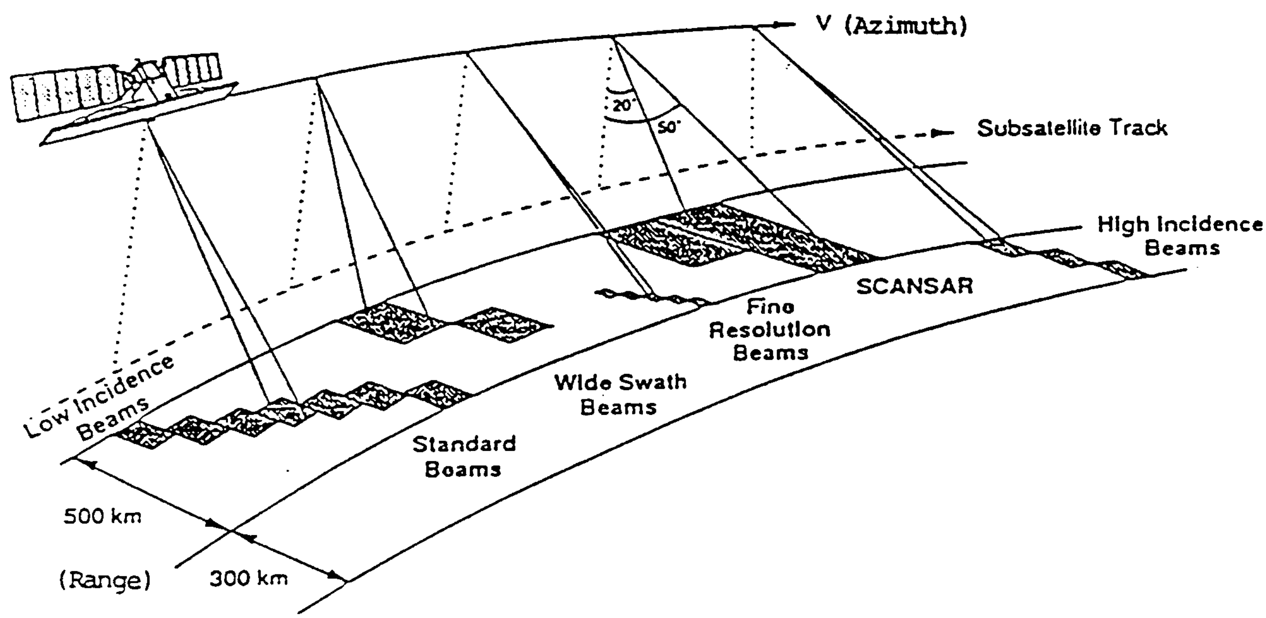

Figure 2. RADARSAT Modes of Operation.

ICEC has first priority on assignment of times in the schedule. The search assignments are frozen one week in advance. The ICEC has concluded that the ScanSAR(W) mode will not be able to detect icebergs on a regular basis. It is possible that RADARSAT may provide early imaging of large icebergs upstream. To date, no one

has explored the possibility of using a finer resolution mode. It is not known whether sufficient access could be provided on a regular basis to provide coverage of the IIP area of interest.

Access to processed RADARSAT images is provided through RADARSAT International, Inc.. At this time, the estimated processing cost is $1000-1400 per image. Final agreement has not yet been reached on how the 15% allocation to the U.S., managed by NASA, will be assigned, and what the processing cost implications would be.

7.3.2 *Other satellite systems.* ICEC currently uses E-ERS-1 and NOAA AVHRR images in its sea ice program. The AVHRR images are infrared and hence dependent on visibility. the AVHRR swath width is 2700 KM with a resolution of 1.1 x 1.1 km. Clearly, even without clouds, AVHRR would not provide a reliable means of detecting icebergs. The E-ERS-1 C-band (VV polarization) SAR resolution is much better, approximately 30 m, but it has a smaller swath width of 80 km. It is unlikely that either system will contribute to iceberg detection.

7.4 Ground-based Technology Alternatives

7.4.1 *Groundwave radar*. Northern Radar Systems Limited has built a prototype High Frequency Ground Wave Radar system at Cape Race, Newfoundland. Northern Radar claims nominal detection range of 125 nm for large icebergs. They have planned a major upgrade to provide 150 nm detection of small icebergs and 250 nm detection of large icebergs. The system is also supposed to provide for measurement of surface currents, waves and sea state, and surface wind. ICEC evaluated the GWR performance comparing their reports with the results of IIP flights in the same area on May 30 - June 1, 1992 (Power, undated). The conclusion of the study is that there was little correlation between the Cape Race GWR reports and the IIP observations. The cost of the information and data format are unknown.

7.4.2 *SOSUS.* A second ground based alternative is the use of the installed SOSUS system. Unlike whales or submarines, icebergs do not make consistent sounds that permit reliable identification. It appears that the sensor locations and the inability to accurately identify icebergs make this alternative unlikely to be able to accomplish the mission objectives.

7.5 Unmanned Airborne Technology Alternatives

7.5.1 *U.S. Army UAV.* The U.S. Army is developing an Unmanned Aerial Vehicle (UAV) with the following specifications: 24 hours continuous coverage at 500 nm range; altitude range from 3,000 to 25,000 ft; and a payload capacity of 450 pounds. An extended range capability is being developed as is a deicing capability. The UAV is operated with a ground control station and datalink. The estimated system cost is $10M.

7.5.2 *AMERIND "Predator"*. AMERIND is currently developing a UAV as a technology demonstration project for the Undersecretary of Defense. The drone, termed the "Predator," will cover 500 nm at an altitude up to 25,000 ft. and will loiter up to 60 hour in an area. The drone carries a Westinghouse SAR. A ground control station must be located at the airport where the vehicle takes off and lands. The GCS must be operated by a licensed pilot. The drone currently has no deicing capability. It is the size of a large Cessna. System cost is approximately $13M for four vehicles and a GCS. The vehicle flies on a satellite which requires purchasing channels and time for communications links.

7.6 Manned Airborne Technology Alternatives

7.6.1 *USCG surveillance*. This alternative continues the current operation, but explores alternative ways of improving the effectiveness of that operation. As indicated in an earlier section, an RCP has been approved for installation of GPS in the HC-130 aircraft. The AN/APS-135 SLAR radar is scheduled to be upgraded with a digital processor in the near future. The recent experience in the joint use of the AN/APS-137 FLAR with the installed SLAR suggests better performance (Ezman, Murphy, Fogt, and Reed, 1993). It has not been determined how that better performance may impact issues such as selection of the search area. Additionally, new FLAR enhancements for periscope mode imaging may provide additional identification capability. Finally, the cost and effectiveness of available SAR systems such as the STAR-2 would be investigated.

7.6.2 *Canadian surveillance*. Appendix A presents an overview of Canadian ice operations. One of the selected management alternatives for Phase II is Canadian Management of the IIP. One element of that alternative would be for Canada to provide the surveillance necessary to generate the ice information. A separate alternative would involve continued U.S. management of IIP (presumably the Coast Guard) with surveillance contracted to Canada. As indicated in Appendix A, the ICEC Dash-7 will have excess capacity with the arrival of RADARSAT. ICEC is interested in identifying new business opportunities for the Dash-7. Given the permanent location in Gander, ICEC suggests that they may be able to perform the surveillance mission at a lower cost than deploying a HC-130 to St. John's. In addition, they would have more flexibility in choosing when to fly to take advantage of visibility and thereby improve the identification/classification problem. ICEC would be willing to modify the sensor suite to meet the mission requirements. If RADARSAT images did yield valuable iceberg information, ICEC would be in a position to provide that information directly.

7.6.3 *Commercial contracted surveillance*. As another alternative, contracting surveillance to commercial firms is technically feasible. Both Intera Technologies Limited and Atlantic Airways Limited provide ice surveillance to ICEC. As indicated above, Atlantic Airways is the single largest contributor to IIP sightings. Intera Technologies completes its contract with ICEC in March, 1995.

7.6.4 *DOD surveillance.* A final source of surveillance is the Department of Defense. Historically, DOD assets have been available on special occasions. It is unlikely that they could be committed on a regular basis to conduct iceberg surveillance flights.

7.7 Selected Surveillance/Detection/Classification Alternatives

The satellite systems offer little promise in the near future for assisting in the detection of icebergs in the IIP area of responsibility. Certain aspects of RADARSAT may be useful for supplemental information and should be examined further.

The ground based systems appear to be very marginal. The upgrade to the Cape Race GWR should be examined in more detail and appropriate costs identified. It may have a role as a supplemental source of information.

Neither of the UAV systems are sufficiently well developed. The initial costs are significant and the operating costs (pilots, maintenance, etc.) are not known. Further analysis at this time is not appropriate.

DOD airborne surveillance is not feasible on a regular and cost-competitive basis. Certain radar decisions (use of AN/APS-131 SLAR on HC-130H aircraft) have been made for CG surveillance based on cost and standardization concerns. Nonetheless, the effectiveness of the resulting system has to be evaluated and opportunities for operational savings identified. Finally, the possibility of contracting surveillance is a viable alternative. In order to pursue this in a meaningful way, it will be necessary for CIIP and the Program Manager to be involved in developing a meaningful performance requirement for the surveillance task.

In summary, after evaluating the above alternatives, and based on the evaluation criteria, the following alternatives were selected for detailed analysis in Phase II:

① Brief examination of RADARSAT and Ground Wave Radar systems.

② USCG HC-130 surveillance using SLAR/FLAR combinations and possibility of SAR installation.

③ Surveillance contracted to Canada (ICEC).

④ Surveillance contracted to commercial firms (Atlantic Air, Intera Technologies).

8.0 Selection of Alternatives for COEA.

The detailed COEA in Phase II will include a complete examination of the existing system and will likely generate additional alternatives in the context of improvements and refinements to the existing system. In addition to the current system, Phase II will include the alternatives summarized below.

8.1 Selected Management Alternatives

Phase II will identify the costs and effectiveness associated with the following management alternatives:

① U.S. management with Coast Guard assigned responsibility (current system).

② Canadian management. Because of the need to amend SOLAS to incorporate this alternative, it will be approached as U.S. management (Coast Guard) with all work contracted to Canada..

③ U.S. management with National Ice Center assigned responsibility. This alternative assumes that NIC will assume all IIP functions.

8.2 Selected Modeling Alternatives

Phase II should focus on conducting a detailed sensitivity analysis of the system and develop an approach to characterize the risk posture for the IIP. The results will be used to assist in evaluating the effectiveness of different alternatives. If this analysis identifies particular problems with specific data inputs, alternative methods of acquiring more reliable data should be evaluated. The analysis may also identify the areas of potential refinement of existing models and the need for some validation.

8.3 Selected Data Acquisition and Processing Alternatives

Phase II should examine the requirements for integrating the CG version of the ADAM system into IIP surveillance aircraft. In addition, Phase II will include a general comparison/evaluation of both upgrading the INTERGRAPH system and the use of the Canadian ISIS system for data processing.

8.4 Selected Surveillance/Detection/Classification Alternatives

The following alternatives were selected for detailed analysis in Phase II:

① Brief examination of RADARSAT and Ground Wave Radar systems.

② USCG HC-130 surveillance using SLAR/FLAR combinations and possibility of SAR installation.

③ Surveillance contracted to Canada (ICEC).

④ Surveillance contracted to commercial firms (Atlantic Air, Intera Technologies).

8.5 Composition of Alternatives

The alternatives identified for further analysis in Phase II are decomposed into unit levels. The resulting data will permit a reasonable composition of these building blocks to form other proposals. For example, surveillance may be provided by a combination of contracted Canadian and commercial sources. Ground wave radar may be used to provide coverage in a portion of the area of responsibility and airborne surveillance may be used in other portions.

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APPENDIX A

Overview of Canadian Ice Information Management Operations

A comprehensive description of Canadian ice information management operations can be found in *MANIS* (Atmospheric Environment Service, 1992). The information presented here is based on a site visit to Ice Centre Environment Canada (ICEC) on October 4-5, 1994. The primary sources of information were Ms. Anne O'Toole, Director, Ice Services, AES, and Mr. Terry Mullane, Chief, Ice Forecast Services, ICEC.

ICEC has the primary task of assessing the current condition of ice (primarily sea ice) in Canadian waters to facilitate the movement of shipping. The primary customer of their service is the Canadian Coast Guard which expects current and accurate information to permit effective deployment of icebreakers. A significant portion of the ICEC budget is provided on a reimbursable basis from the CCG. Ice Services employs about 70 personnel with 30 in ICEC operations.

The primary focus is on sea ice. ICEC receives satellite images from the NOAA AVHRR satellites and from E-ERS-1. These are processed on a number of workstations. ICEC also has a contract (which expires in March, 1995) with Intera Technologies to provide surveillance of sea ice in various areas, primarily in the Gulf of St. Lawrence. Intera operates a Challenger jet with two McDonald-Detweiller Associates SAR radars. In addition, ICEC operates a SLAR equipped Dash-7 aircraft that is also configured for visual search. The Dash-7 typically operates off the east coast of Newfoundland and identifies icebergs as well as sea ice during routine operations. ICEC also receives sea ice and iceberg information from Atlantic Airways aircraft which fly fisheries patrols over the Grand Banks for the Department of Fisheries and Oceans (DFO). ICEC will also contract separately with Atlantic Airways to conduct ice surveillance flights when needed. All aircraft conducting surveillance for ICEC use 100% coverage.

The new element in ICEC data acquisition is the expected launch in Summer, 1995 of RADARSAT. The RADARSAT system is owned by the Candian Space Agency with NASA receiving 15% of the images over the first two years in exchange for the launch. A separate firm, RADARSAT International has exclusive rights to process and sell images. For ICEC, the RADARSAT images will provide an all weather capability to detect sea ice and eliminate the need for the Intera jet and reduce the need for the Dash-7. In the ScanSAR(W) mode which ICEC intends to use for sea ice detection, there is little chance that RADARSAT will detect icebergs. Ms. O'Toole indicated that under the present arrangements, ICEC would not be able to share RADARSAT images directly with IIP without recovering the royalty payment to RADARSAT International. However, data that is extracted from RADARSAT images (e.g., iceberg locations) could be shared. The estimated cost of a processed image is $1,000-1,400.

In order to facilitate processing of multiple images, ICEC has a current project to develop an Ice Services Integrated System (ISIS). A conceptual overview of the project

is included in Appendix B. The proposed system will fully integrate the satellite image processing, SAR/SLAR aircraft imagery, and all environmental data on a geocoded/ georeferenced basis. ICEC will standardize on HP 9000 workstations for this system.

Using a development grant, ICEC has developed the iceBerg Analysis and Prediction System (BAPS) in order to track icebergs in their area of interest. This system incorporates the IIP drift and deterioration models and was transferred to the IIP in the INTERGRAPH system (Data Management and Prediction System--DMPS). ICEC uses one of the regular sea ice forecasters to operate BAPS (6-9 month assignment) and produce one ice bulletin and ice chart each day. ICEC uses the LAKI established by the IIP when the IIP is in operation. The ISIS is structured to incorporate BAPS, probably in 1996. ICEC uses the same iceberg sighting data as IIP. They also use the FNOC SST and wave height and period data. However, they use Canadian Meteorological Center (CMC) wind data instead of the FNOC data used by IIP. Operation of BAPS will depend on the particular operator. A common approach to resights is using a "fence resight" in the interior of the LAKI rather than examine each reported sighting as does IIP. In a fence resight, a border or fence is created around a set of reported sightings and all of those sightings replace any icebergs or radar targets in the same area on the current plot. Some ICEC operators reportedly do use the individual approach rather than fence resights.

There appear to be several opportunities for increased Canadian involvement in the IIP. The current director sees this as a natural evolution with the IIP operating the ICERECDET out of a Canadian location and covering Canadian waters. There is a tendency to believe that it should be a Canadian operation. With RADARSAT coming on line, there will be excess capacity in the Dash-7 aircraft. Ms. O'Toole is interested in finding a means of using that capacity and covering the large fixed costs. She believes that the Dash-7 could effectively perform the surveillance function to determine the LAKI at a lower cost than the Coast Guard. Both Ms. O'Toole and Mr. Mullane see an advantage in using an aircraft that is permanently in the area and can take advantage of visual flying weather to improve the detection and classification/identification of icebergs. The main caveat in our discussions was the issue of cost. The impression was that Canada would be willing to conduct the surveillance, and even operate the entire program if their costs were fully covered. It is appropriate to identify their costs and the Coast Guard's actual costs to determine if either surveillance or management is a viable option.

APPENDIX B

Ice Services Integrated System Conceptual Overview

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ISIS

Ice Services Integrated System Conceptual Overview

Prepared by:
Awtar Koonar
Project Manager

The contents of this paper may not be copied in other documents without reference.

1.0 Introduction:

The Ice Services Integrated System (ISIS) is being developed to:

- replace the existing Ice Data Integration and Analysis System (IDIAS);
- implement the Radarsat data processing and analysis capability;
- provide a common Human Machine Interface (HMI) for all Ice Centre applications;
- replace the Flight Planning System (FPS);
- replace the NOAA Data Request System (NDRS);
- provide an architecture framework for ensuring that all development work is consistent
- maximize the reusability of already developed objects or components and
- provide cost effective solution for system development and maintenance life cycle.

This system will be mainly used by the Ice Forecasters, Ice Analysts and System Operators and maintained and enhanced by the Ice Centre informatics group. The system must be flexible, expandable, upgradable and reliable for meeting Ice Centre's requirements of the 1990's and beyond.

The Ice Centre has developed the software architecture to be used by this project and any future development and replacement projects. The reusability and maintainability of developed code are of great importance. This system will be designed using object oriented design and analysis methodology and off-the-shelf packages fitting into the Ice Services architecture framework.

The ISIS will be comprised of a number of sub-systems. These sub-systems include: data acquisition, data processing & image analysis, Work Station sub-system (data display and chart production, etc.), data storage and dissemination.

The Data Acquisition sub-system will be responsible for acquiring data from a number of sources. These data sources will include the Ice Reconnaissance aircraft SAR/SLAR, the Radarsat satellite to be launched in 1995, the ERS-1 satellite until Radarsat is fully operational, NOAA-11, 12 and 13 satellites, SSM/I satellite, other Ice Centre systems, Canadian Meteorological Centre, the Ice and national AES archives, Canadian Coast Guard Ice breakers and Ice Operation Offices and United States Coast Guard.

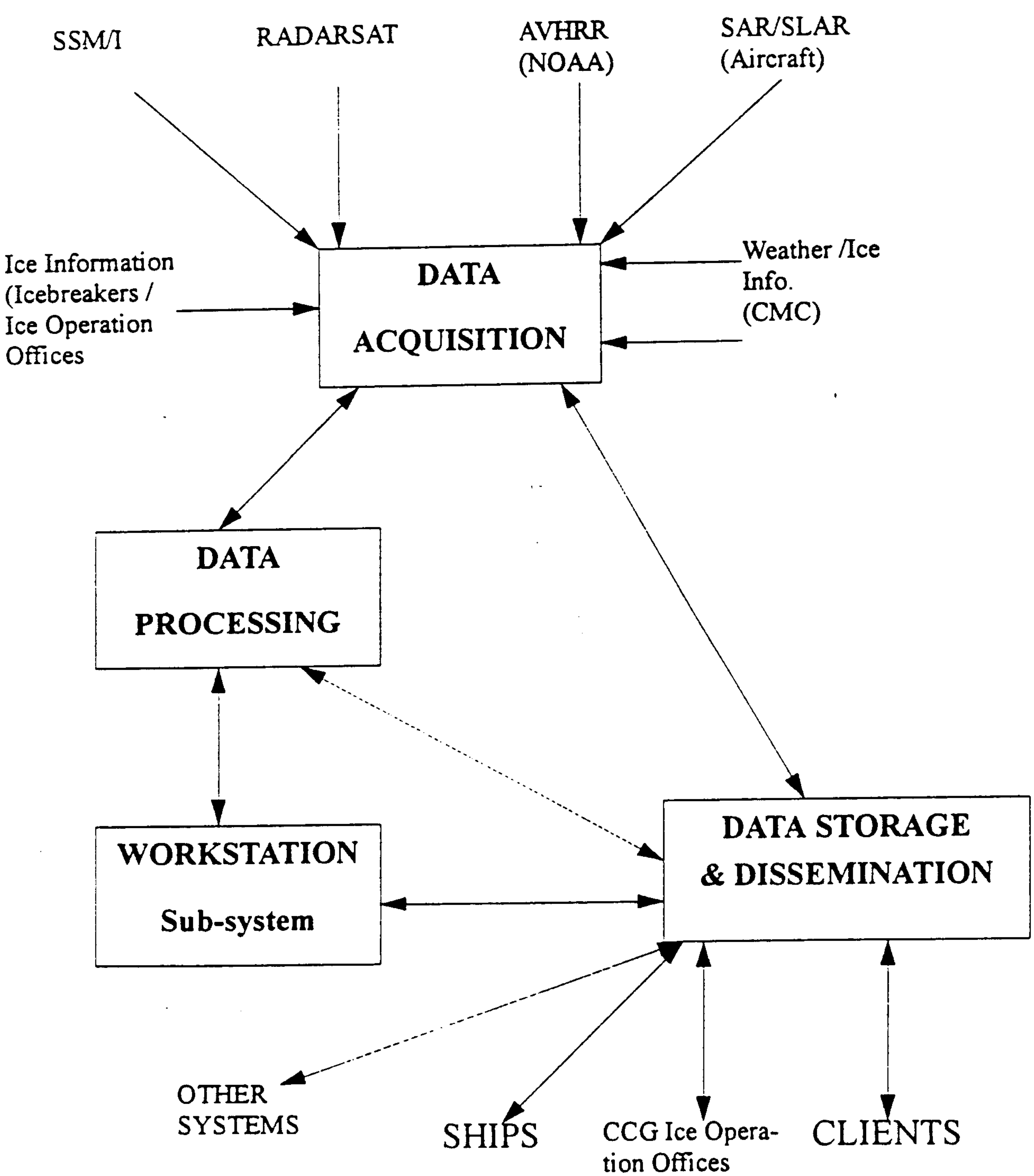
The Data Storage and dissemination sub-system will store acquired, processed and other associated data of all data types spatially. This sub-system will be responsible for ensuring the data integrity, data security and data access to users or application software. The dissemination component will be responsible for disseminating ice related products and data to other systems as well as to Ice Services clients.

The Data processing sub-system will process all acquired image, graphic and alphanumeric information including: geocoding/georeferencing data; automatic and manual image analysis; and automatic or manual image data classification. Image Analysis and manipulation capabilities will be provided by an off-the-shelf integrated image analysis/GIS package.

The Data display and chart production sub-system will be responsible for: display and manipula-

tion of image data received in real-time, scanned data, graphic and alphanumeric data; chart production including all easy-to-use chart creation and editing capabilities; and GIS functionality.

The ISIS Project Plan provides a detailed overview of the Ice Centre real-time operations and project objectives including standards.


SSM/I
RADARSAT
AVHRR
(NOAA)
SAR/SLAR
(Aircraft)
Ice Information
(Icebreakers /
Ice Operation
Offices
DATA
ACQUISITION
Weather /Ice
Info.
(CMC)
DATA
PROCESSING
WORKSTATION
Sub-system
DATA STORAGE
& DISSEMINATION
OTHER
SYSTEMS
SHIPS
CCG Ice Opera-
tion Offices
CLIENTS

2.0 System Architecture Framework:

The ISIS development will be based on:

- client/server architecture using distributed database;
- architecture framework based on object oriented methodology;
- global services for all Ice Centre common functions such as print/plot, communications, database access, etc.;
- X.11, Motif standards;
- TCP/IP and NFS over Ethernet and ATM or FDDI networks;
- C & C++ development languages;
- HP-9000/755 (or later) workstations with CRX-24 display or later technology with multiple displays;
- HP-9000/755 or 800 series servers with Disk arrays and fault tolerant architecture;
- Oracle database; and
- FrameMaker documenting package.

All off-the-shelf packages must demonstrate compliance with the Ice Centre architecture framework and must be easily integrability with other off-the-shelf packages and custom software.

The software architecture and repository architecture documents provide detailed descriptions of this architecture.

3.0 Final System Functional Overview:

It is essential that all vendors understand the operational view of the ISIS including reliability, performance, expandability and maintainability issues.

This system will be used for assisting the Ice Forecasters and Ice Analysts for performing real-time ice forecasting operations. The detailed description of operational scenarios can be found in the ISIS work flow scenarios.

The ISIS can be visualized as a multi-server/multi-workstation system using a distributed data-base, ingesting and processing large amounts of image, graphical and alphanumeric data in real-time and assisting in the analysis of data, product preparation and dissemination.

3.1 Servers

The *servers* can be visualized as performing the following functions:

- receive real-time image, graphical and alphanumeric information from different platforms;
- schedule multiple processors for processing data using an intelligent load balancing and load sharing technique for taking maximum advantage of free CPU power;
- provide an optional waterfall display of the SAR/SLAR and AVHRR data for review and preview purposes;
- provide access to raw NOAA data;
- store this information in the common database schema;
- geocode and georeference imagery data using either pre-defined ground control points or geographical information embedded in the data;
- store geocoded/georeferenced information for today while retaining processed imagery for the previous five to thirty days. The storage scheme will be such that any user can access imagery from any workstation and view large images quickly using tiling technology;
- advise the workstation about arrival of image data either through painting a graphical directory of coverage or updating image list of the workstation;
- perform pre-defined enhancements on processed imagery and advising workstations on availability of different enhancements;
- execute ice tracking and classification algorithms and updating workstation data list with further processed imagery and tracking vectors;
- serve workstation for providing access to all data sets in the ISIS environment
- provide global services such as: inter-system communications, print/plot, database access, etc.;
- route messages (image, graphics, alphanumeric) to the dissemination systems or destinations and confirmation of message delivery to the originator;
- keep audit trail up-to-date;
- purge expired data sets;
- keep database synchronized in an enterprise wide client/server architecture;
- provide seamless data exchange linkages with CIDAS and AES weather archive system.

3.2 WORKSTATION

The workstation environment is updated with arriving data sets required by this workstation. The workstation public storage is available to all clients and servers for viewing and copying purposes. Three types of workstations will be setup, e.g. high powered operational workstations (HP-9000/700 series), medium powered workstations for development, training and project work and PC based workstations. The medium based workstations such as Alpha based or low cost workstations such as 486 based must be suitable for field use. The GIS/Image analysis software operating on medium or low cost workstations must have similar Human Machine Interface capabilities and the data exchange between all three types of workstations must be transparent.

The workstations can be viewed as performing the following functions:

- Display images, charts, model results and alphanumeric information on any screen in any view at a selected scale;
- create or edit an ice chart with automatic polygon closing, polygon hatching and shading, egg placement, filling and validation;
- analyze AVHRR, Radarsat, ERS-1 or 2, Aircraft SAR/SLAR and SSM/I imagery in a continuous mode and generate image analysis products for the entire area of coverage or for sub-areas;
- provide capabilities to the user to: view historical or archived ice charts; flip multiple images in a single view; display two or more images in opaque mode and one or more charts in the same view; mosaic; view image classification, tracking or modelling output;
- generate ice forecast charts by applying model results;
- set up and execute animation sequences and loops;
- initiate models, ice tracking or classification or other applications from the work station;
- tailor HMI to individual tastes;
- view archive catalogue and select data sets required for the work station;
- generate or modify production schedules;
- print/plot data sets or products on different output devices;
- disseminate products or messages to selected destinations;
- prepare flight plan mission graphically;
- prepare satellite data requests using different orbit models graphically;
- prepare special products (image or chart) for tactical support;
- view data acquisition and billing statistics;
- maintain message/product distribution lists;
- provide grid contouring capability;
- display modelled ice charts in 2-D or 3-D;
- prepare bulletins through already developed applications;
- scan other charts or display faxed charts;
- add multi-media capabilities to ice charts for automated briefing purposes;
- display weather charts and information;
- correct (X/Y shift) or rotate images;
- classify in an interactive mode using image classification techniques;

- tune system to support changing needs of the operations;
- research new image enhancement techniques;
- display buoy/beacon tracks; and
- display surface temperature data in textual or graphical form.

The Detailed overview of workstations and services is described below:

3.3 Setup:

Log on to any workstation with a preassigned account or as an ad-hoc user specifying area of interest. The pre-assigned account will contain default area of coverage desired.

Once the user is successfully logged on, the servers will load all the image, weather and graphical information as required by the default setup. All default or system menus (in absence of default menu) will be displayed with default data sets, e.g., yesterday's ice chart, today's image data, today's weather information and data request coverage overview will be updated identifying the availability of remotely sensed data. This data will stay resident in the workstation's database for at least 24 hours.

3.4 IMAGE ANALYSIS:

The user must be able to display different image sets on two or more screens in different views or windows with chart information displayed in another view. As the user pans or zooms through the current chart, all the views or windows are panned or zoomed in synchronization.

Some of the common functions required by different image analysis mode are: manipulation of lookup tables, displaying histograms for any image; selecting interactive enhancement such as three way linear stretch based on histogram for enhancing image features; repositioning of menus at any area of the screen in order to maximize screen real- estate; rotation of an image; spatial modelling whereby the user can define steps required, preferably graphically, to enhance an image.

3.5 AVHRR Analysis:

The user will be able to display three bands with different colors assigned to each band in normal mode or linearly stretched or a pre-enhanced image. The system will display the full image and then the user will be able to zoom different areas by using the roam box. The roam and pan will let the user navigate through the entire image. The analysis can be done in both full image or zoomed mode whereby the image analysis chart can be prepared. An example of the image analysis chart is attached. The analyzed imagery and image analysis chart will be made available to all workstations and server for view and copy purposes. The enhancements based on histograms can be performed and the spatial modelling capability will also be available.

3.6 SAR/SLAR Analysis:

The user will be able to display the full aircraft coverage. The default display will be the coverage in his/her area of interest but the user will be able to navigate through the SAR/

SLAR images outside his area of interest. The analysis will be based on a leg by leg basis. The user will start with any flight leg analysis and will be able to analyze the entire leg or sub-set of a leg by navigating through the imagery in a continuous fashion. The North directional arrow should be displayed for easy positioning and referencing. Again, the enhancements based on histograms can be performed and the spatial modelling capability will also be available. As different parts of the flight leg are analyzed and saved, other users will be able to view or copy the SAR/SLAR analysis for integration or quality control purposes.

3.7 Radarsat Data Analysis

Ice Centre is planning to receive about 2.5 GB of radarsat imagery per day. Each Radarsat scene will be at least 500x500Km. with 50 m. pixel size and 100 m. resolution. The approximate size of each scene would be 100 MB. The data acquisition, processing and availability of this data, in a timely and reliable manner, to the workstations will be very critical. The data acquisition, geocoding and georeferencing processes are described later on.

One scenario for Radarsat image analysis would be that at least one full scene (georeferenced) will be memory resident in the high powered workstation. The user can then view the entire georeferenced scene on any screen, use a selectable navigating window to zoom to a critical area of interest and start image analysis. On completion of this analysis, the user will be able to pan in any direction, at the same zoom level and scale, to analyze the next image sub-set. The entire analysis must be performed on a continuous basis ensuring that different polygons are properly connected. The user may be able to release different image sub-set analyses to the Ice Centre clients or to other users. The user may be able to perform interactive classification on the entire image set, to get a quick overview of different ice types and ship traffic flow pattern or other clients location requiring service, to determine analysis and product preparation priorities. This feature must be available in all image analysis cases.

For other workstations, medium and low cost, this capability may be available through central database probably using a tiling technique or in a stand-alone mode.

3.8 SSM/I Data Analysis:

The Ice Centre receives SSM/I information from the Canadian Meteorological Centre (CMC) on a regular basis. The information can arrive either in a grid format or raster format. The workstation will be able to display either contours based on the grid data or an image. It is very important that all the data must be georeferenced and scaled to the parameters selected by a workstation, e.g., one workstation might be viewing information in 1:1M and other in 1:2M, etc. All the image or graphic information is displayed to this workstation selected scale.

3.9 Image Opaque Capability:

The user will be able to display images and graphics in multiple display layers, all visible at the same time. The top layer may be the chart or graphic information, the second layer may be an AVHRR image in opaque mode, the third layer Radarsat image, and so on.

3.10 Image Rotation and Correction:

The user will be able to rotate the image through a rotation guide to fit the image with the underlying image or graphic information. The image correction may be only an X Y shift. The correction may be done using the drag and drop or point and click method. Provision for updating the entire image set based on a selected X Y shift is required.

3.11 Image Flipping:

Most of the image data required by a workstation will be stored locally as well as on the server. The local storage is important to ensure optimum workstation performance. The image data will be kept in physical as well as cache memory to meet a less than one second image flipping requirement.

3.12 Image Animation:

Any user will be able to set up animation loops, sequences and dwell times for animating image sets or ice charts. The animation may be performed in full resolution (1024x1024) or a reduced resolution. The user will be able to animate both monochrome and full color images or charts.

3.13 Interactive Classification:

The user will be able to define signatures interactively and save these for later use. Furthermore, the user will be able to perform ice classification using these signatures or initiating other classification algorithms. The resulting image may be used for dissemination purposes to the Ice Centre clients.

3.14 Image Synchronization:

As described earlier, if a number of views are open for the same area of coverage then pan or zoom actions in one view must refresh other views for geographical synchronization. The user will be able to de-synchronize these views any time.

3.15 FAX charts or Scanned Charts:

The user will be able to scan any chart or image into the system. The scanned chart must be geographically referenced for integrating information into the current ice chart. The faxed charts will be available in the system.

3.16 Image Mosaic capability:

The user will be able to display multiple images and generate a mosaic image.

4.0 GRAPHICS RELATED FUNCTIONS AT THE WORKSTATION:

The user will be able to create, edit, archive or delete ice charts as described below; copy, cut and paste lines, symbols, polygons or a fenced area to another window or view or drag and drop these elements in the same view; and prepare flight tracks, alphanumeric bulletins and data request messages. A number of editing devices such as puck, mouse and stylus must be supported. A digitizing tablet with a stylus is presently the preferred approach.

4.1 Create and edit ice chart:

A number of scenarios can be used at the work station.

Scenario 1: The user starts with yesterday's ice chart and updates this chart by copying information from other charts such as modelled forecast chart, ice breaker chart and imagery chart. In this scenario, cut/paste/move/delete elements or group functionality is required. The drag and drop or point and click devices are required to support this functionality.

Scenario 2: The user starts with yesterday's chart and uses imagery chart to update parts of the ice chart. The user uses a digitizing tablet and stylus to complete the rest of the chart.

Scenario 3: The user starts from scratch by loading a base map of the area of interest and performing absolute or relative registration of the working ice chart on the physical screen and using a stylus to draw the ice chart in a natural fashion, e.g., pen & paper concept.

During this chart preparation a number of additional functions are required which are specific to the Ice Centre. As the user is drawing polygons, it is desired that the polygons be automatically closed based on a user selectable capture area. During the chart production process, the user can turn on or off the egg mode. An egg is automatically displayed at the most suitable location after the polygon is closed when the egg option is turned on. When egg mode is off, the user continues drawing polygons and triggers egg mode during or at the end of the polygon drawing process.

The workstation will insert centroids in all completed polygons and a symbol set of different egg shapes are displayed when egg mode is turned on. The user will be able to select an appropriate ice egg and click the destination location. Following this process, the egg values can be inserted using a keypad or think pad. Once the egg is filled, the contents of the egg are validated. This process continues until the user turns egg mode off.

During chart production, a number of different data sets will be available in the workstation and the user should be able to turn any of these data sets on or off for reference or copying purposes. The option of using a thinkpad may be required. Using the thinkpad, the user may be able to enter different egg values or special symbols.

The user will be able to define and apply polygon hatching, shading or coloring patterns based on pre-defined rules. The rules can be defined using a spreadsheet type approach.

4.2 Contouring:

A grid contouring capability must be available to the workstation. The system operator or a development user must be able to define the grid for contouring purposes and the workstation will be able to display this information.

4.3 Triggering Models or other applications:

The user will be able to create icons for triggering any application throughout the Ice Centre computing facility and AES wide computing facility. The system must be easily tunable to allow such capability.

4.4 Flight Planning Module:

In the flight planning mode, the user might have displayed a number of images with wide area coverage.A number of symbols (such as airports, ships, IRDNET stations) will be positioned in the working view (top view) along with ship tracks, sea ice and iceberg limits. The second view may contain imagery in opaque mode while a third view contains another image set. The user uses a string type approach to draw a flight track, leg by leg with default swath coverage (optional). Upon completion, a graphical and alphanumeric product is prepared for dissemination and automatically disseminated upon approval.

4.5 Image Data Request:

A number of orbit models will be available to the workstation for determining satellite data requests. These models will include AVHRR and Radarsat and the system must be flexible enough to add other orbit models.

The user will display the orbit coverage in his/her area of interest and will select start and stop points for data required from a particular satellite pass. The system must display the ordering units (e.g., segments) applicable to the individual satellite. This process will continue until the data request is complete. It is possible that a number of pre-defined requests may already be present in the system. In this case, the existing data requests will be displayed on the workstation and the user may be able to modify or cancel these requests and issue new requests, if required.

If data requests for the same data source are done from a number of workstations then the collaborator (server) will try to arrange these requests in a contiguous manner, e.g., data requests from two workstations for the same areal coverage will be considered as one request. These data requests will be forwarded to the data acquisition person to resolve any other conflicts.

The data requests can be viewed at any workstation in a graphical or a tabular manner. Data requests for different sensors are sent to different satellite receiving platforms and the server must packet these requests in the required format and disseminate to the appropriate station. Upon receiving acknowledgment from receiving sites, the workstation(s) expected data sets list should be updated. These data lists are used for reviewing remotely sensed coverage by the Ice Forecaster.

The user may be able to assign priorities to different sub-orbits (or sections) being requested from different sensors and the server will use these priorities during the image processing phase if required, e.g. in case of an overload situation.

The data requests for a longer period (six month) can be done at the beginning of a season and the system will automatically send these requests to the satellite receiving stations. The user has the option of overriding these requests any time.

4.6 Models

Ice and Iceberg models provide objective guidance to Ice Forecasting Operations. These models may run automatically or may be initiated by the user. The user will be able to initiate models or other algorithms such as ice tracking for his/her area of interest and display results. Furthermore, the user may be able to apply model outputs to current ice chart to verify the forecast.

4.7 Weather Display:

The user must be able to use other applications to display weather (Synoptic, ships, SA's, etc.), or beacon information on any screen. These applications are required to be compatible with the architecture framework.

The user may be able to display a basemap with desired weather or climate stations or ships and optionally the latest weather report or the user may click on any station or ship to get detailed information. Optionally, the user may be able to display graphs of temperature and degree days for any station or a group of stations.

4.8 Bulletin Preparation:

The user must be able to call blank forms and/or previous bulletins and use a standard message composition package to prepare the forecast and then disseminate it to destinations.

4.9 Product Dissemination:

The user will be able to select destinations for product delivery, initiate the dissemination and upon successful delivery get delivery confirmation. The user will be able to add, delete and modify destinations.

4.10 Archive/De-archive:

All products will be retained on the operational database for a specified period and in the archive database for a number of years. These products will be deleted from the operational database on expiry of the specified retention period.

Whenever the user requires a dataset, for review or copy purposes, the software will retrieve this information from the operational or archive data base and supply it to the requesting workstation. This access must be seamless.

5.0 DEVELOPMENT ACTIVITIES FROM A WORK STATION:

A development interface available from the workstation HMI may be used (based on security) to perform operational tuning, HMI changes, activating/deactivating different geographical regions, setting new production schedules for producing automatic image enhancements, or cleaning up the data base. An easy-to-use interface must be provided to carry out these functions.

6.0 MAINTENANCE ACTIVITIES FROM THE WORKSTATION:

The development interface can also be used to monitor process execution, data flow and for diagnosing problems. The problem may be rectified by using the operator interface or by fixing bugs through the development environment. The operator interface may be used for tuning system parameters, stopping and starting processes, queue management, etc.

7.0 BACKGROUND FUNCTIONS

7.1 COMMUNICATIONS:

The ISIS will be based on a client/server architecture. In such an architecture, the networking and external communications are critical for providing a reliable and acceptable solution. The system must support TCP/IP, NFS, Ethernet 802.3, FDDI and ATM protocols. ATM is expected to mature by the end of 1993. It will be the preferred protocol for ensuring that multi-media requirements are met.

The system must be able to: handle incoming data from high speed networks while ensuring data integrity; route information to other systems; and disseminate products or data to different clients. Radarsat data will be received from the Gatineau receiving facility in near real-time via a T1 or T3 link using FTP format. The Radarsat data can also arrive from the Joint Ice Centre via a 56Kb/s link using X.25 and FTP formats. The internal formats of Radarsat data arriving from the two sources may be different.

NOAA-11, NOAA-12 or NOAA-13 data will be received from HRPT stations in Halifax and Edmonton via a 56Kb/s link. The aircraft SAR/SLAR data will be received via IRDNET in real-time at a 384Kb/s rate.

The Ice Centre is also connected to the AES Wide Area Network. This network uses X.25 and frame relay technology for data exchange. All the weather related information is received via this network and all ice products are also disseminated to clients via this network. Information is also exchanged with the Ice Centre clients via Telex and Fax.

7.2 RELIABILITY:

Dual Redundancy:

In order to provide a reliable and fail safe solution, it is essential that the down time be minimized and performance maximized. In order to achieve this, faster disk interfaces, faster disk drives, fully loaded servers with Raid disk technology and redundancy at critical components level or software supported redundancy is required.

Database Synchronization:

In a distributed database system, it is critical that the entire database is synchronized. The server must have up-to-date information on all datasets resident throughout the network. The datasets being generated by a workstation must be saved by the servers on a regular basis to minimize productivity loss.

Alerts:

The system operator and user must be alerted about system problems and a help function must be provided to rectify the problem.

7.3 Hardware/Software Maintenance and support:

This hardware support must be available locally with a minimum four hour response time.The telephone software support must be available seven days a week. The software

subscription service must be available from all vendors.

7.4 Database:

At present, the Climatological Ice Data Archive System (CIDAS) is using an Oracle database and the AES national archive is using Oracle database as well. The WSO workstation uses Empress database with Neon's Application Program Interface. The Ice Application Software utilizes Empress with global library interface. All off-the-shelf packages seem to support Oracle, Sybase and Informix databases but support for Empress is not generally available. Some analysis for using the correct database with a robust Application Programming Interface capability will be performed.

The Arc Storm and the Oracle Multi Dimension data bases are the leading contenders in handling spatial databases.

7.5 Integration:

The integration of all off-the-shelf or custom applications must be compliant with the Ice Centre architecture framework in order to ensure incremental build and operational integration objectives are met.

7.6 Geocoding and Georeferencing:

It must be possible to geocode or georeference remotely sensed data by setting background processes or queues and maximizing image processing turn around time by scheduling and managing processes in multiple processors. The development user must be able to set up production schedules interactively, easily and must be able to simulate the resulting output. Different geocoding or georeferencing packages may be used for ensuring that production throughput requirements are satisfied.

Georeferencing/geocoding must be available in the background mode. Upon acquisition of remotely sensed data, an intelligent load balancing algorithm must be able to initiate geocoding or georeferencing processes on different data sets. As these processes are completed, the workstations are sent required geocoded/georeferenced information.

It must be possible to geocode/georeference images in an interactive mode for development purposes by using rectification and rubber sheeting techniques.

7.7 Print/Plot:

Any user will be able to plot any image on any compatible output device. Safeguards must be built to ensure operational priority is not compromised. There may be some printers dedicated to operational use only.
Any user must be able to generate reports or graphs and direct output to any compatible output device.

7.8 Reformatting:

The system must be able to handle a number of plotting, graphical or raster formats and must be able to perform format conversions. Some of these formats are: TIFF, PCX, Flat

image files, HP-GL, JPEG, GIF, etc.

7.9 Compression:

The system will be required to store large volumes of data, it is important that compression options for storage and retrieval of data are explored, in a loss less mode.

7.10 Mailboxes:

The system must be able to utilize mailboxes capabilities of bulletin board systems. Using this mailbox, a user may be able to request different data sets and products and the system should be able to deliver these products to a mailbox.

7.11 Bulletin Board System:

The system will be able to deposit all products or requested data required by the AES clients into a bulletin board system. The clients will be able to dial-in to this bulletin board to retrieve required products or data.

7.12 Data/Product delivery monitoring:

It must be possible to enquire or alter the status of any incoming or outgoing data or product. Optionally, the user may be able to turn on product graphical tracking mode.

7.13 HELP

Context sensitive help and help tutorials must be available.

8.0 PERFORMANCE REQUIREMENTS:

At each workstation, some of the typical performance requirements expectations are:

- Ice chart production within 30 minutes.
- chart plot within 3 to 5 minutes.
- image flipping mode - image display within 1 second.
- image rotation within 2 minutes.
- image load and display within 4 seconds.
- status enquiry within two seconds.
- complete chart polygon formation within 2 minutes.
- geocoding of one NOAA image within 5 minutes (Automatic)
- georeferencing a Radarsat scene within 10 minutes (Automatic)
- roam/zoom/scale instantaneous performance
- image display (first screen) within one second and subsequent screens - same as roam/zoom.

Detailed performance requirements can be found in the ISIS requirements document.

APPENDIX C

Preliminary Sensitivity Analysis of IIP Iceberg Deterioration Model
prepared by
Stephen A. Joseph

OBJECTIVE

In this analysis we study the propagation of errors through the Iceberg Deterioration Model. We examine the relative impacts of the uncertainties and errors in measurement of different input parameters on the model's predicted output parameter or response as a consequence. Assumptions made are that all inputs are empirical quantities and that their uncertainties can be represented by (Gaussian?) probability distributions. The main objective is to determine, with respect to uncertainty, those parameters that tend to have the greatest impact on the model response in different scenarios. As we are interested in the influence of these parameters one-factor-at-a-time, their various interaction effects were not taken into account. Thus we conduct a univariate parametric sensitivity analysis. This analysis will help guide us as to whether or not it is worthwhile to gather measurements that would yield more precise and/or accurate data (perhaps via different technologies) or possibly to refine the model itself.

ICEBERG DETERIORATION MODEL

The Iceberg Deterioration Model (Anderson, 1984) consists of four additive components that contribute to deterioration by way of heat transfer. SUN represents insolation; BUOY represents bouyant convection; WINFO represents wind forced convection; and WAVE represents wave induced deterioration. Seven variables are incorporated into these four components:

x_1 = SST (Sea Surface Temperature in °C)
x_2 = XAMP (Wave Height in cm)
x_3 = RELSPD (Relative Speed in cm/s)
x_4 = RLEN (Waterline length in m)
x_5 = IPER (Wave Period in s).
x_6 = ZTIME (in half days)
x_7 = WEATHER (0 = CLEAR, 1 = CLOUDY).

The four components expressed as functions of these seven variables are then:

SUN = 2*WEATHER*0.5*ZTIME/100
(WEATHER = 1)
(ZTIME = 2)

BUOY = $0.274*(2.78T + 0.47T^2)*0.5*$ZTIME/100
(T = SST - Iceberg Surface Temperature)
(Iceberg Surface Temperature was held constant at -1°C)

WINFO = FC*T*0.5*ZTIME/100
FC = $(0.66 - 0.151*\log_{10}$RLEN)*(RELSPD-25) +
$(0.934 - 0.202*\log_{10}$RLEN)*25 (RELSPD > 25)
FC = $(0.934 - 0.202*\log_{10}$RLEN)*(RELSPD) (RELSPD < 25)

WAVE = XAMP*0.000146*$(2/\text{XAMP})^{0.2}$*24*3600*(T/IPER)*0.5*ZTIME/100

or
SUN = $2*x_7*0.5*x_6/100$

BUOY = $0.274*[2.78*(x_1 + 1) + 0.47(x_1 + 1)^2]*0.5*x_6/100$

WINFO - FC $*(x_1 + 1)*0.5*x_6/100$

$$FC = (0.66 - 0.151*\log_{10}x_4)*(x_3-25) + (0.934 - 0.202*\log_{10}x_4)*25 \qquad (x_3 > 25)$$

$$FC = (0.934 - 0.202*\log_{10}x_4)*x_3 \qquad (x_3 < 25)$$

WAVE = $x_2*0.000146*(2/x_2)^{0.2}*24*3600*[(x_1 + 1)/x_5]*0.5*x_6/100$

The total deterioration, MELTis given by

$$Y = SUN + BUOY + WINFO + WAVE$$

or

$$Y = f(x_1, x_2, x_3, x_4, x_5, x_6, x_7)$$

For the analysis, $x_6 = 2$ and $x_7 = 1$.

METHODOLOGY

The model was initially inspected to determine the factor or factors believed to constitute the major contribution to deterioration. An initial *nominal range sensitivity analysis* was performed to determine the factor that was dominant in the majority of different scenarios. Once this dominant factor was discovered its value alone was varied to present three different "nominal" scenarios. Within these scenarios, further univariate parametric sensitivity analysis was performed to determine how uncertainties in the other factors propagate through the model. This information would be captured by perturbing their values from the "nominal" within a plausible range. The relative contributions to the uncertainty in the output could then be determined.

RESULTS

The factors which constituted the major contribution to uncertainty were sea surface temperature SST, and wave height XAMP. A nominal range sensitivity analysis was performed by changing their values by ten percent. It was found that SST was the dominant factor in the majority of scenarios. However, it should be noted that at low SST, XAMP was dominant. Therefore, three different SST's were used to dictate the three different "nominal" scenarios: 1, 6, and 15°C. The nominal values of the other factors remained constant from one scenario to another:

x_2 = XAMP = 6 ft (182.9 cm)
x_3 = RELSPD = 25 cm/s
x_4 = RLEN = 100 m
x_5 = IPER = 10 s
x_6 = ZTIME = 2 half-days
x_7 = WEATHER = 1

Only XAMP, RELSPD, and IPER were perturbed uniformly by fifty percent, forty percent, and fifty percent respectively, while RLEN was varied by classification and with much more disparity. Thus, in all cases, misclassification obviously had the greatest effect on uncertainty in melt rate. Therefore as common sense dictates, XAMP, RELSPD, and IPER were considered together in terms of their relative uncertainties.

Results show that at an SST of 1°C, changes in XAMP had the greatest effect on the deterioration, followed by IPER. In fact, the uncertainty in XAMP propagated roughly thirty percent more uncertainty as IPER. RELSPD had an almost negligible effect.

Results at an SST of 6°C were similar. Uncertainty in XAMP propagated roughly twenty percent more uncertainty. Again, changes in RELSPD had an almost negligible effect. At an SST of 15°C, results were almost identical to those at 6°C. A more detailed account of uncertainty propagation classified by factors follows:

EFFECTS ON MELT RESPONSE

Sea Surface Temperature:

An SST of 1°C resulted in a MELT of 2.176
If incorrectly measured at 0.9°C, the predicted response MELT, Y = 2.068.
If incorrectly measured at 1.1°C, the predicted response MELT, Y = 2.284, which means that **4.96% extra MELT would be nonexistent.**
Refer to table 1a and figure 1a for more details.

An SST of 6°C resulted in a MELT of 7.609
If incorrectly measured at 5.4°C, the predicted response MELT, Y = 6.954.
If incorrectly measured at 6.6°C, the predicted response MELT, Y = 8.266, which means that **8.63% extra MELT would be nonexistent.**
Refer to table 2a and figure 2a for more details.

An SST of 15°C resulted in a MELT of 17.55
If incorrectly measured at 13.5°C, the predicted response MELT, Y = 15.88.
If incorrectly measured at 16.5°C, the predicted response MELT, Y = 19.23, which means that **9.57% extra MELT would be nonexistent.**
Refer to table 3a and figure 3a for more details.

Wave Height:

A 6 ft (182.9 cm) wave height at SST = 1°C resulted in a MELT of 2.176:
If incorrectly measured at 164.6 cm, the predicted response MELT, Y = 2.024.
If incorrectly measured at 201.2 cm, the predicted response MELT, Y = 2.324, which means that **6.80% extra MELT would be nonexistent.**
Refer to table 1a and figure 1a for more details.

A 6 ft (182.9 cm) wave height at SST = 6°C resulted in a MELT of 7.609:
If incorrectly measured at 164.6 cm, the predicted response MELT, Y = 7.080.
If incorrectly measured at 201.2 cm, the predicted response MELT, Y = 8.128, which means that **6.82% extra MELT would be nonexistent.**
Refer to table 2a and figure 2a for more details.

A 6 ft (182.9 cm) wave height at SST = 15°C resulted in a MELT of 17.55:
If incorrectly measured at 164.6 cm, the predicted response MELT, Y = 16.34.
If incorrectly measured at 201.2 cm, the predicted response MELT, Y = 18.74, which means that **6.78% extra MELT would be nonexistent.**
Refer to table 3a and figure 3a for more details.

EFFECTS ON NUMBER OF DAYS TO ACHIEVE 100% MELT

Wave Height:

A 6 ft (182.9 cm) wave height at SST = 1°C ***(45 - 46 days to achieve 100% melt):***
If incorrectly measured at 3 ft (91.44 cm), the number of days predicted for 100 % melt would be 70 - 71 .
If incorrectly measured at 9 ft (274.3 cm), the number of days predicted for 100% melt would be 34 - 35, which would mean that the iceberg would be considered **nonexistent for 11 days.**
Refer to table 1b for more details.

A 6 ft (182.9 cm) wave height at SST = 6°C ***(12 - 13 days to achieve 100% melt):***
If incorrectly measured at 3 ft (91.44 cm), the number of days predicted for 100 % melt would be 20 - 21.
If incorrectly measured at 9 ft (274.3 cm), the number of days predicted for 100% melt would be 9 - 10, which would mean that the iceberg would be considered **nonexistent for 3 days.**
Refer to table 2b for more details.

A 6 ft (182.9 cm) wave height at SST = 15°C ***(5 - 6 days to achieve 100% melt):***
If incorrectly measured at 3 ft (91.44 cm), the number of days predicted for 100 % melt would be 8 - 9.
If incorrectly measured at 9 ft (274.3 cm), the number of days predicted for 100% melt would be 4 - 5, which would mean that the iceberg would be considered **nonexistent for 1 day.**
Refer to table 3b for more details.

Wave Period:

A 10s wave period at SST = 1°C *(45 - 46 days to achieve 100% melt);*
If incorrectly measured at 5s, the number of days for 100% melt would be 24 - 25, which would mean that the iceberg would be **nonexistent for 21 days.**
If incorrectly measured at 15s, the number of days for 100% melt would be 62 - 63.
Refer to table 1c for more details

A 10s wave period at SST = 6°C *(12 - 13 days to achieve 100% melt);*
If incorrectly measured at 5s, the number of days for 100% melt would be 7 - 8, which would mean that the iceberg would be **nonexistent for 5 days.**
If incorrectly measured at 15s, the number of days for 100% melt would be 17 - 18.
Refer to table 2c for more details

A 10s wave period at SST = 15°C *(5 - 6 days to achieve 100% melt);*
If incorrectly measured at 5s, the number of days for 100% melt would be 3 - 4, which would mean that the iceberg would be **nonexistent for 2 days.**
If incorrectly measured at 15s, the number of days for 100% melt would be 7 - 8.
Refer to table 3c for more details

Relative Speed:

A 25 cm/s relative speed at SST = 1°C *(45 - 46 days to achieve 100% melt):*
If incorrectly measured at 15 cm/s, the number of days for 100% melt would be 47 - 48.
If incorrectly measured at 35 cm/s, the number of days for 100% melt would be 43 - 44, which means that the iceberg would be **nonexistent for 2 days.**
Refer to table 1d for more details.

A 25 cm/s relative speed at SST = 6°C *(12 - 13 days to achieve 100% melt):*
If incorrectly measured at 15 cm/s, the number of days for 100% melt would be 13 - 14.

If incorrectly measured at 35 cm/s, the number of days for 100% melt would be 12 - 13, which means that the iceberg would be **nonexistent for 0 days.**
Refer to table 2d for more details.

A 25 cm/s relative speed at SST = 15°C *(5 - 6 days to achieve 100% melt):*
If incorrectly measured at 15 cm/s, the number of days for 100% melt would be 5 - 6.
If incorrectly measured at 35 cm/s, the number of days for 100% melt would be 5 - 6, which means that the iceberg would be **nonexistent for 0 days.**
Refer to table 3d for more details.

Waterline Length:

A 122 m (medium) iceberg at SST = 1°C *(55 - 56 days to achieve 100% melt);*
If misclassified as 60 m (small) the number of days for 100% melt would be 26 - 27, which means that the iceberg would be **nonexistent for 29 days.**
If misclassified as 225 m (large) the number of days for 100% melt would be 103 - 104.
Refer to table 1e.

A 122 m (medium) iceberg at SST = 6°C *(15 - 16 days to achieve 100% melt);*
If misclassified as 60 m (small) the number of days for 100% melt would be 7 - 8, which means that the iceberg would be **nonexistent for 8 days.**
If misclassified as 225 m (large) the number of days for 100% melt would be 29 - 30.
Refer to table 2e.

A 122 m (medium) iceberg at SST = 15°C *(6 - 7 days to achieve 100% melt);*
If misclassified as 60 m (small) the number of days for 100% melt would be 3 - 4, which means that the iceberg would be **nonexistent for 3 days.**
If misclassified as 225 m (large) the number of days for 100% melt would be 12 - 13.
Refer to table 1e.

"Nominal Values":

SST = 1°C
XAMP = 6ft = 182.9cm (1ft = 30.48cm)
RLEN = 100m
IPER = 10s
RELSPD = 25cm/s
ZTIME = 2 (½days)
WEATHER = 1

TABLE 1A [10% Changes in SST and XAMP: Effect on MELT]

SST	XAMP	MELT
0.9	164.6	1.924
1.0	164.6	2.024
1.1	164.6	2.125
0.9	182.9	2.068
1.0	182.9	2.176
1.1	182.9	2.284
0.9	201.2	2.208
1.0	201.2	2.324
1.1	201.2	2.439

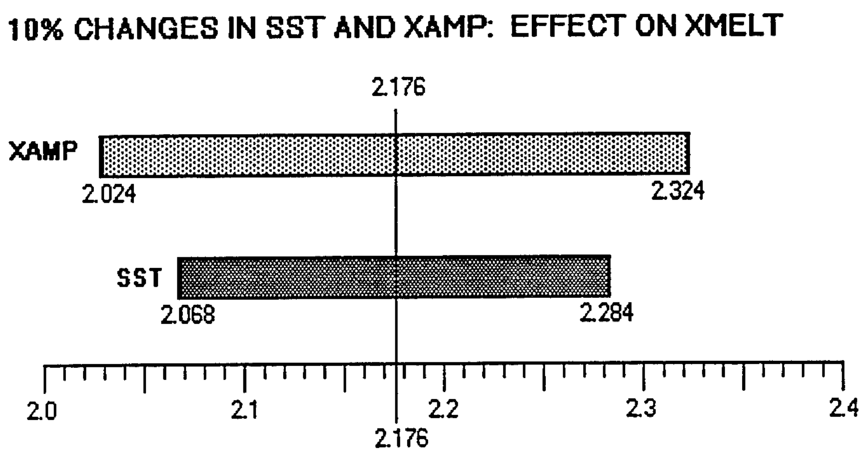


FIGURE 1A

TABLE 1B [Varying XAMP 50% (3ft - 9ft):]

XAMP	#DAYS TO MELT
91.44	70 - 71
121.9	58 - 59
152.4	50 - 51
182.9	45 - 46
213.4	40 - 41
243.8	37 - 38
274.3	34 - 35

TABLE 1C [Varying IPER 50% (5s - 15s):]

IPER	#DAYS TO MELT
5	24 - 25
6	28 - 29
7	33 - 34
8	37 - 38
9	41 - 42
10	45 - 46
11	48 - 49
12	52 - 53
13	56 - 57
14	59 - 60
15	62 - 63

TABLE 1D [Varying RELSPD 40% (15cm/s - 35cm/s):]

RELSPD	#DAYS TO MELT
15	47 - 48
17	47 - 48
19	46 - 47
21	46 - 47
23	45 - 46
25	45 - 46
27	44 - 45
29	44 - 45
31	44 - 45
33	43 - 44
35	43 - 44

TABLE 1E [Varying RLEN0:]

RLEN0	#DAYS TO MELT
60	26 - 27
122	55 - 56
225	103 - 104

"Nominal Values":

SST = 6°C
XAMP = 6ft = 182.9cm (1ft = 30.48cm)
RLEN = 100m
IPER = 10s
RELSPD = 25cm/s
ZTIME = 2 (½days)
WEATHER = 1

TABLE 2A [10% Changes in SST and XAMP: Effect on MELT]

SST	XAMP	MELT
5.4	164.6	6.470
6	164.6	7.080
6.6	164.6	7.691
5.4	182.9	6.954
6	182.9	7.609
6.6	182.9	8.266
5.4	201.2	7.428
6	201.2	8.128
6.6	201.2	8.829

10% CHANGES IN SST AND XAMP: EFFECT ON XMELT

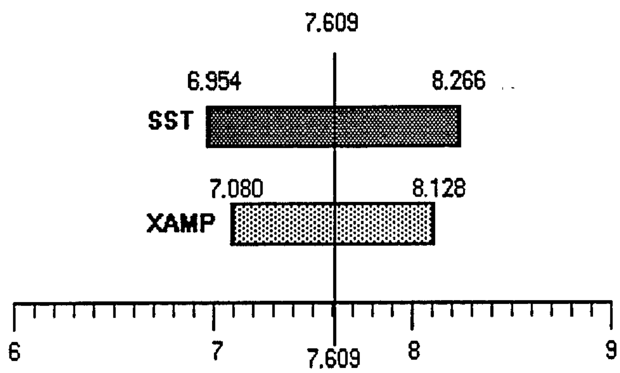


FIGURE 2A

TABLE 2B [Varying XAMP 50% (3ft - 9ft):]

XAMP	#DAYS TO MELT
91.44	20 - 21
121.9	16 - 17
152.4	14 - 15
182.9	12 - 13
213.4	11 - 12
243.8	10 - 11
274.3	9 - 10

TABLE 2C [Varying IPER 50% (5s - 15s):]

IPER	#DAYS TO MELT
5	7- 8
6	8 - 9
7	9 - 10
8	10 - 11
9	11 - 12
10	12 - 13
11	14 - 15
12	15 - 16
13	16 - 17
14	17 - 18
15	17 - 18

TABLE 2D [Varying RELSPD 40% (15cm/s - 35cm/s):]

RELSPD	#DAYS TO MELT
15	13 - 14
17	13 - 14
19	13 - 14
21	13 - 14
23	13 - 14
25	12 - 13
27	12 - 13
29	12 - 13
31	12 - 13
33	12 - 13
35	12 - 13

TABLE 2E [Varying RLEN0:]

RLENO	#DAYS TO MELT
60	7 - 8
122	15 - 16
225	29 - 30

"Nominal Values":

SST = 15°C
XAMP = 6ft = 182.9cm (1ft = 30.48cm)
RLEN = 100m
IPER = 10s
RELSPD = 25cm/s
ZTIME = 2 (½days)
WEATHER = 1

TABLE 3A [10% Changes in SST and XAMP: Effect on MELT]

SST	XAMP	MELT
13.5	164.6	14.78
15.0	164.6	16.34
16.5	164.6	17.91
13.5	182.9	15.88
15.0	182.9	17.55
16.5	182.9	19.23
13.5	201.2	16.96
15.0	201.2	18.74
16.5	201.2	20.53

10% CHANGES IN SST AND XAMP: EFFECT ON XMELT

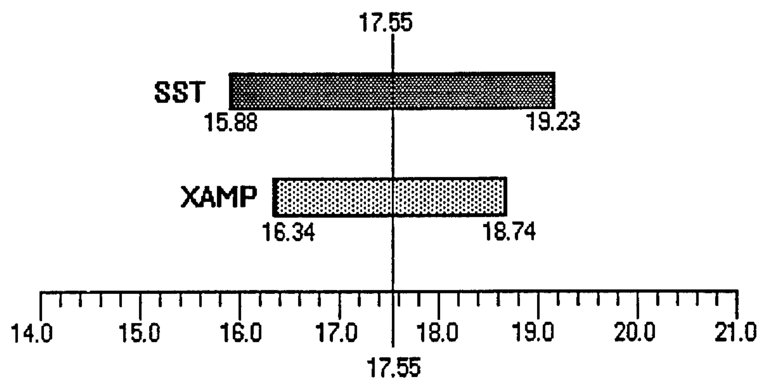


FIGURE 3A

TABLE 3B [Varying XAMP 50% (3ft - 9ft):]

XAMP	#DAYS TO MELT
91.44	8 - 9
121.9	7 - 8
152.4	6 - 7
182.9	5 - 6
213.4	5 - 6
243.8	4 - 5
274.3	4 - 5

TABLE 3C [Varying IPER 50% (5s - 15s):]

IPER	#DAYS TO MELT
5	3 - 4
6	3 - 4
7	4 - 5
8	4 - 5
9	5 - 6
10	5 - 6
11	6 - 7
12	6 - 7
13	6 - 7
14	7 - 8
15	7 - 8

TABLE 3D [Varying RELSPD 40% (15cm/s - 35cm/s):]

RELSPD	#DAYS TO MELT
15	5 - 6
17	5 - 6
19	5 - 6
21	5 - 6
23	5 - 6
25	5 - 6
27	5 - 6
29	5 - 6
31	5 - 6
33	5 - 6
35	5 - 6

TABLE 3E [Varying RLENO:]

RLENO	#DAYS TO MELT
60	3 - 4
122	6 - 7
225	12 - 13

TABLE 4A [Varying SST:]

SST	#DAYS TO MELT	#DAYS TO MELT (FROM TABLE C-3)
-1	—	179.0
-0.5	175 - 176	—
1	45 - 46	—
3	22 - 23	20.5
6	12 - 13	12.0
10	8 - 9	8.0
15	5 - 6	5.0

TABLE 4B [Varying SST by ±½°C:]

SST	#DAYS TO MELT
2.5	25 - 26
3.0	22 - 23
3.5	20 - 21
5.5	13 - 14
6	12 - 13
6.5	12 - 13
9.5	8 - 9
10	8 - 9
10.5	7 - 8
14.5	5 - 6
15	5 - 6
15.5	5 - 6